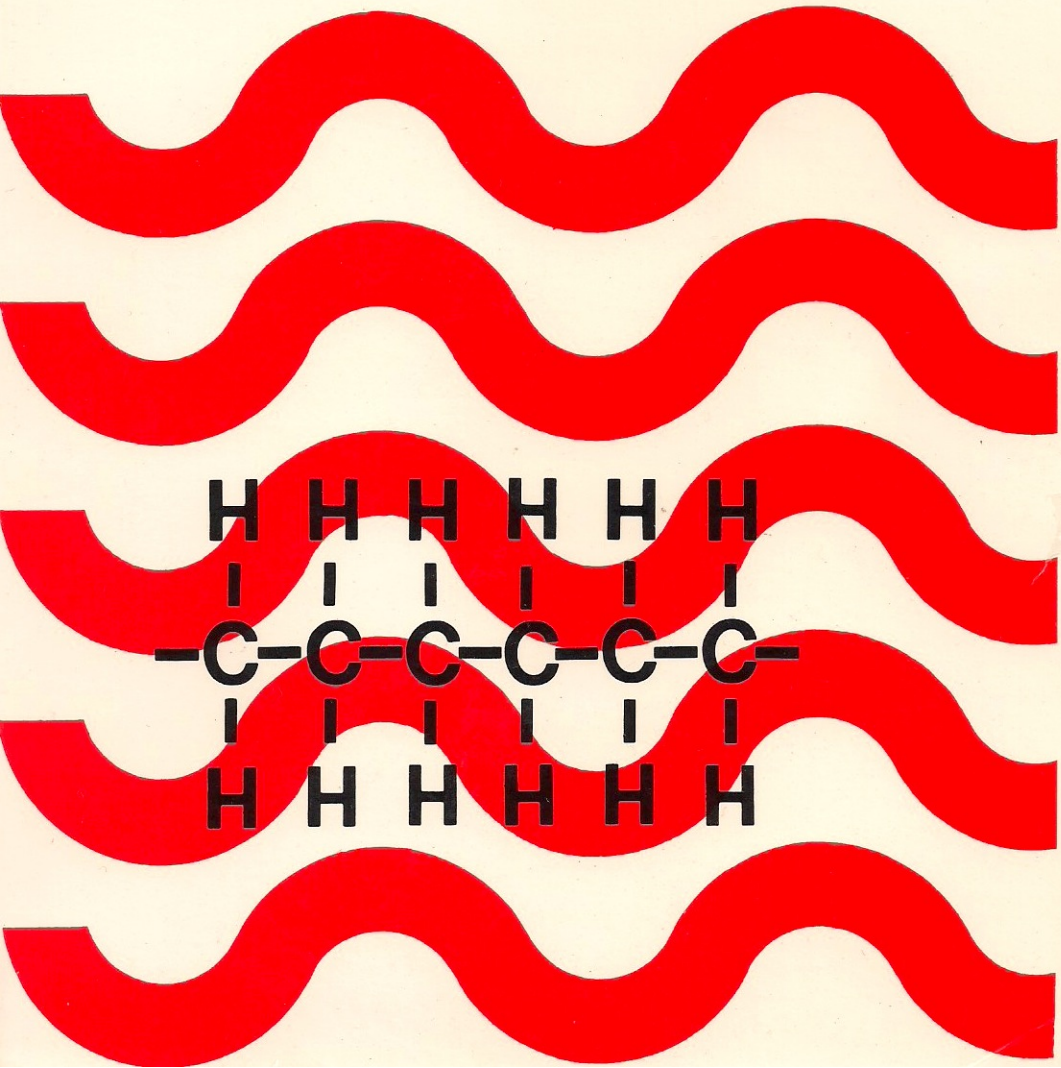
SCIENTIFICALLY SPEAKING



Scientifically Speaking

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An Introduction to the English of Science and Technology

Adviser and Editor:

B. C. Brookes, Reader in Information Studies in the University of London

Dialogues by

Bob Kesten

Production by

Viola Huggins

English by Radio and Television
The British Broadcasting Corporation

SCIENTIFICALLY SPEAKING

First Publication in Great Britain

Printing History
B.B.C. edition published 1971

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This book is set in 11 on 12 pt. Photon Times by
Richard Clay (The Chaucer Press), Ltd., Bungay, Suffolk
and printed by
Fletcher & Son, Ltd., Norwich, Norfolk

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Acknowledgements

The British Broadcasting Corporation wishes to thank the following for generous assistance in the preparation of this book:

Plastics	The British Plastics Federation
Steel	The Inter-Group Laboratories of the British Steel Corporation
Aircraft	'Flight International' British Aircraft Corporation Britten-Norman Ltd.
Nuclear Power	The United Kingdom Atomic Energy Authority The Central Electricity Generating Board
Oil	Esso Petroleum Co. Ltd.
Civil Engineering	The Institution of Civil Engineers Binnie & Partners, Consulting Engineers
Electronics	The Institute of Computer Science 'Electronics Weekly'
Shipbuilding	The Shipbuilding Industry Board The Shipbuilders and Repairers National Association The British Shipbuilding Research Association
Computers	Computer Enterprises Ltd. The Institute of Computer Science The General Electric and English Electric Companies Ltd.
Telecommunications	The Post Office Corporation

Preface

'*Scientifically Speaking*' is a short introduction to the English written and spoken by scientists and engineers. The book shows the specialized English of science and technology in use, and gives examples of many words which are frequently found in a number of scientific and technological fields.

After a general introduction on technical English, there are twelve chapters, each of which deals with a particular technological subject by means of written texts, diagrams and conversations. The most useful vocabulary items from the chapters are studied in detail. There is also a general vocabulary at the end of the book. A special appendix comments on some of the grammatical structures and sentence patterns commonly used by scientists and engineers which occur throughout the book.

The reader is not expected to be an expert in the subjects dealt with in the book. He needs to have a knowledge of elementary science and mathematics, but the technical subject matter of the book is presented in a way that will be of interest to the specialist and non-specialist alike. Since the technical and semi-technical words which occur in the English texts are studied in detail or appear in the general vocabulary, the book can be used without the help of a technical dictionary.

The Recordings

This book is intended to be used with recordings issued by the B.B.C. on 7″ LP discs (or tapes, or cassettes). They consist of the twelve conversations printed in the book and the equations and formulae on pages 125, 126 and 127. The principal characters in the conversations; the scientific journalist, Giles Newton and his wife Susan, will be familiar to audiences of the B.B.C. English by Radio series '*Scientifically Speaking*'.

A series of recorded drills and oral exercises based on the lessons for class-room and language laboratory use, is also on sale in many countries. Full particulars are available from English by Radio and Television, B.B.C., Queen's House, 28 Kingsway, London, W.C.2.

Introduction

I. Technical English

WHAT IS TECHNICAL ENGLISH?

When you read a piece of technical writing in English for the first time, or when you first hear scientists or engineers talking in English, you may find it very difficult to understand what is written or spoken, particularly if you have learned English as a language of everyday conversation and of literature. You may think that there is a special kind of English which is used only in science and technology and which has to be learned as a separate language. You may also feel that somehow the English of science and technology is much more difficult than everyday English. In fact, technical English does differ from everyday English, because of the specialized contexts in which it is used and because of the specialized interests of scientists and engineers. But the differences do not present any great problems once they have been recognized.

The following passage illustrates some of the features of technical English:

(Mr. Smith enters Dr. Brown's office. Dr. Brown is a consultant. Dr. Brown speaks.)

DR. BROWN **Good morning, Mr. Smith. Can I take your coat? Awful weather, isn't it? Do sit down. Cigarette?**

MR. SMITH **No, I don't smoke, thanks very much.**

DR. BROWN **Well, I've been looking into your enquiry about the corrosion trouble you've been getting in the control valve. I'm sorry you've had trouble—quite unexpected—but I think we have the answer. The most probable cause of corrosion at a metal-to-metal junction immersed in an ionized fluid is electrolytic.**

In this passage, Dr. Brown begins by talking informally to his visitor, but when he talks as an expert about his specialized subject—corrosion—his way of

talking changes. His statements are impersonal, his style of speech is formal and he uses many technical terms.

Now here is an example of technical writing in English.

The main results obtained were:

(1) If an oscillatory motion was superimposed on steady shearing, the maximum torque on the top plate during the combined motion was scarcely more than the torque in steady shearing alone; the minimum was considerably less. The average torque was much less in the combined motion and it is possible that the average rate at which work was absorbed was less in the combined motion than in the steady shearing alone.
(A later analysis has shown an increase in these two cases.)

(2) The response of the material to oscillatory motion was non-linear below about 20 c/s in these experiments.

For a shear rate of the form:

$$s = s_0 \cos \omega t \qquad (1)$$

The stress was of the form:

$$= \sum_{n=1} A_{2n-1} \cos \{(2n-1)\omega t - \phi_{2n-1}\} \qquad (2)$$

The whole of this passage is in an impersonal, formal style, with a very high concentration of technical terms and a number of mathematical symbols (see also page 125). Some of these characteristics of technical English are examined in the sections which follow.

IMPERSONAL, OBJECTIVE STATEMENTS AND ATTITUDES

Scientists and engineers are interested in things and processes, in properties and characteristics. They are also trained to be objective. They endeavour to make statements or observations on which all observers would agree, and to make agreement easier they express many of their observations in numbers or by meter readings.

A non-scientist may be content to say that he can see a green light when he looks into an optical instrument. But 'green' is a subjective word and green is a colour of many possible shades. Verbal descriptions of colour given by different observers do not agree closely. So a scientist prefers to describe a colour by

stating its wavelength, or its range of wavelengths and their intensities, because wavelengths and intensities can be read on the scales of suitable meters by anyone who is not blind. A scientist always invites others to verify his descriptions of what he observes. He accepts as facts only impersonal, objective statements about things which can be seen by any observers who choose to look.

This objective attitude is naturally reflected in the way scientists and engineers express themselves and particularly in the kinds of grammatical structures and sentence patterns which they prefer, although the sentence patterns which occur in technical English are also found in non-technical English. Several of the patterns which occur most frequently in technical English are dealt with in the appendix at the end of this book.

II. Technical Vocabulary

SPECIALIZED VOCABULARIES

We have seen that technical English uses grammatical and syntactic forms and patterns which also occur regularly outside technical English. There are no new forms or patterns to be learned. However, the vocabulary of any technical discussions or piece of writing may include words which are never used outside the subject or field in question. If you do not know the subject, you will not understand what is said or written, even if English is your mother tongue. This is not surprising. Specialized vocabularies are not confined to science and technology. There is a specialized vocabulary of ballet and a specialized vocabulary of cricket. You are unlikely to understand a conversation between ballet enthusiasts or cricket enthusiasts unless you know something about ballet or about cricket. But the vocabularies used in science and technology are very large, and in English they include many semi-technical or non-technical words which are used in unfamiliar ways so that their new meanings must be learned.

TECHNICAL WORDS

As the range of knowledge and achievement increases in any scientific or technological field, new terms are needed to define new phenomena and to explain new things and processes. Often suitable terms have to be invented. Scientists have been extending the vocabularies of their subjects for centuries and each subject has its own store of terms with precise, narrow meanings (e.g. *bandwidth*,

flip-flop, *semiconductor*, *solenoid*). Clearly it is not necessary to know *all* the separate technical vocabularies in order to deal with even very difficult technical reports or publications in one particular field. A physiologist will want to know one set of terms, an electrical engineer another. Moreover many of these highly technical terms are adopted internationally with only slight variations, usually to allow for differences in pronunciation or in word forms from one language to another. For example:

ENGLISH	FRENCH	GERMAN
electrolysis	electrolyse	Elektrolse
acetylene	acetylene	Azetylen
condenser	condensateur	Kondensator
magnesium	magnesium	Magnesium
pancreas	pancreas	Pankreas

There are of course many other technical words, particularly the well established names of substances, which differ from one language to another (e.g. English: *iron*, French: *fer*; English: *oxygen*, German: *Sauerstoff*).

Many technical terms are made up from Latin and Greek roots, prefixes and suffixes which soon become familiar (e.g. *ethylene*, *polyethylene*, *polytetrafluoroethylene*, *binomial*, *quadrinomial*). Other technical terms may be made up from existing words whose meaning is well known and is not substantially altered in the technical compound word (e.g. *feedback*, *hovercraft*, *overpass*, *undercarriage*). Sometimes words which are invented for use in one field are later added to the vocabularies of other fields.

Although there are good technical dictionaries which will solve most problems of technical vocabulary, you will find in this book notes on the way in which many technical words are formed, and each chapter contains a number of technical terms relevant to its subject.

SEMI-TECHNICAL WORDS

There are many words whose use is not confined to scientific and technological contexts and which are an essential part of technical English. Some of these are formed from Greek or Latin roots (e.g. *efficiency*, *energy*, *flux*, *moment*), but they are not usually the same in all languages. They include the basic words of the older sciences such as mechanics, and they have usually been taken from everyday language and given a precise definition for scientific use (e.g. *force*, *load*, *mass*, *matter*, *power*, *work*). As a result, the meanings of these words in their

technical use are likely to differ from their non-technical meanings. Moreover, they may have different precise meanings in different technical fields. Thus the word *reaction* might in an everyday context refer to a man's *reaction* to hearing of the death of his wife, while in chemistry it might be used to refer to the *reaction* of ammonia with carbon dioxide to form urea. In nuclear physics it might refer to a nuclear chain *reaction* and in civil engineering it might refer to the *reaction* of a beam against the weight of a load placed on the beam. The wide technical use of words like *reaction* has also led to the introduction of many related forms of a single word (e.g. *to react*, *reaction*, *reactive*, *reagent*, *reactor*, *reactance*). Because these semi-technical words may present difficulties due to their several meanings and because many of them are general in their technical application, and therefore useful in a number of scientific and technological fields, this book will include as many of them as possible, giving examples of their related forms and comparing their different meanings in the word-study sections of the chapters.

FORMAL, NON-TECHNICAL WORDS AND EXPRESSIONS

There remains a class of strictly non-technical words and expressions which are seldom found outside technical English. They have been incorporated into the precise, impersonal, formal English of scientists and engineers partly because they seem to avoid the ambiguity or imprecision of more commonly used words with the same apparent meanings. Thus *to determine* is often used instead of *to find out*, *to convert* instead of *to change*, *appreciable* instead of *a lot of*. There are also expressions like *to be under construction*, *to come under load*, *to come into operation*, which are more common in technical English than in everyday English. There are many examples in this book from this class of words and expressions, and several are featured in the word-study sections.

WORD-STUDY SECTIONS AND VOCABULARY

The word-study sections after most chapters compare useful expressions and words which have similar forms and meanings. They also feature a number of terms from economic and sociological fields, which occur frequently in science and technology. At the end of the book, there is a full vocabulary of the technical and semi-technical terms which occur, with phonetic equivalents.

1. Plastics

The journalist, Giles Newton, and his wife, Susan, are at home after spending the day at a plastics exhibition.

SUSAN NEWTON **I just can't help thinking of things made from plastics as imitations, as cheap substitutes.**

GILES NEWTON **If by 'cheap' you mean less expensive, then you're quite right. For example, that new watering can we bought for the garden.**

SUSAN **Yes, it did cost less than a metal one.**

GILES **Do you remember why we bought it?**

SUSAN **I liked the nice bright yellow colour. But you can buy coloured metal ones, too.**

GILES **Ah! But with plastics, the colour goes all the way through, because the pigments are mixed in with the raw materials. They don't have to be painted like metal.**

SUSAN **What does it matter? The result's the same!**

GILES **No, it isn't. Take a watering can, or a child's toy, or even something you use in the kitchen, like your washing-up bowl. What happens when they're knocked against something hard?**

SUSAN **You mean if they're metal?**

GILES **Yes.**

SUSAN **I suppose, after a while the paint becomes chipped. All right, I see the point. With plastics the colours won't chip off.**

GILES **But do you remember another reason why we decided to buy a new watering can?**

SUSAN **Of course. The old one was so rusty. There were holes in the bottom . . . I see. Plastics don't rust like metal.**

GILES **Exactly. Are you beginning to feel more kindly towards plastics?**

SUSAN **I've nothing against them, Giles, but they are used instead of the original materials, so that makes them substitutes, doesn't it.**

GILES **Do you remember what Mr. Harvey said?**

SUSAN **Who?**

GILES **The plastics expert, you know, the chemist, in the recording I made at the exhibition.**

SUSAN **Oh yes, of course.**

GILES **And, incidentally, my tape recorder wouldn't be so small or so light if it weren't for the fact——**

SUSAN **I know, if it wasn't made of plastics.**

GILES **You're learning. I'll just run the tape back to the right place. I think this is where it is. Listen.**

(*On tape recorder*)

GILES **. . . people who call them substitutes.**

MR. HARVEY **Oh, yes, some still do but they're quite wrong, Mr. Newton. Plastics are materials in their own right. Cheapness is not the only factor that makes them acceptable to industry. Before it can replace any other material—like wood, metal or a natural fabric—a plastics material must have a performance that is at least comparable to whatever was previously used.**

SUSAN **And I suppose sometimes they're even better.**

MR. HARVEY **Frequently, particularly when the properties of the material are adjusted, or even created, to suit the specific requirements of the end product.**

GILES **What sort of properties?**

MR. HARVEY **The degree of rigidity or flexibility, for example; resistance to acids, insulating qualities, ability to withstand sudden changes of temperature. Oh, the list is endless because the plastics industry is being asked continually to recommend or develop materials for such a wide variety of new uses.**

GILES **Do they succeed?**

MR. HARVEY **More often than not. In fact, there are so many types of plastics with so many unique properties, they frequently provide answers to unsolved engineering problems.**

(*Giles Newton stops the tape recorder*)

GILES **Well, Susan?**

SUSAN **He talks so easily about unsolved engineering problems. I'd be more impressed with an example—but a simple one, of course.**

GILES **As simple, perhaps, as your habit of leaving the refrigerator door partly open?**

SUSAN **Well, the catch is broken.**

GILES **Susan! It was repaired two months ago.**

SUSAN **Oh, all right! I sometimes give it a push with my elbow and it doesn't quite close. So?**

GILES **Well, somebody thought of making refrigerators without door-catches. Have you heard of polyvinylchloride—better known as PVC?**

SUSAN **Of course! The upholstery in the car, the kitchen floor tiles, the shower-curtains in our bathroom, they're all different types of PVC.**

GILES **Well, that's what was used to solve this particular engineering problem: PVC, with a magnetic filler.**

SUSAN **So, when the door is almost closed, magnetic attraction pulls it, keeps it tightly shut. That's very clever.**

GILES **And it's cheaper to make.**

SUSAN **And the refrigerator has a better door. Marvellous!**

Plastics are Polymers

Plastics are organic materials which at some stage can be moulded or shaped as required. They are synthetic—man-made, not natural materials, and are composed of long chain-like molecules called polymers. Each of these polymer molecules is formed by joining together many thousands of small molecules called monomers. The monomer molecule is an arrangement of atoms which can be made to react with similar monomer molecules to form a chain. The reaction is known as polymerization.

The monomers from which plastics are made are generally produced by separation from natural gases or from oil. These substances are sometimes combined with other chemicals, such as chlorine. By means of pressure and heat, and often with the aid of catalysts, the monomer molecules of the gas or liquid react and, as they combine, form the polymer molecules of the raw plastics, which is generally in the form of a powder or of granules. By careful control of the polymerization, the monomer molecules may be arranged and joined in a number of ways. Thus the properties of each of the many plastics materials can be modified to suit a wide range of products and applications.

Polymerization

Diagrammatic illustration of polymerization on the following lines:

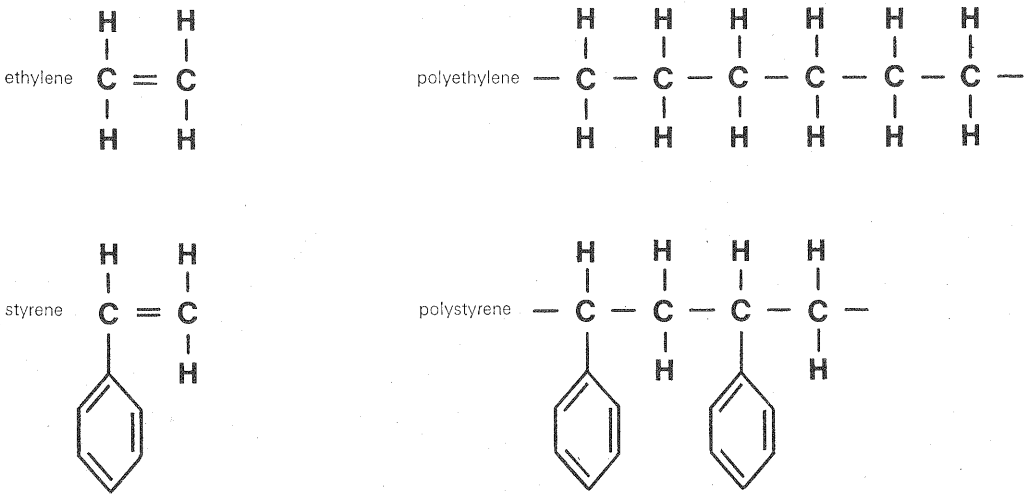


Fig. 1 — Diagram on polymerization

Plastics and Other Materials

(See Word-Study Section 1)

Plastics have specific properties which may make them preferable to traditional materials for certain uses. In comparison with metals, for example, plastics have both advantages and disadvantages. Metals tend to be corroded by inorganic acids, such as sulphuric acid and hydrochloric acid. Plastics tend to be resistant to these acids, but can be dissolved or deformed by solvents, such as carbon tetrachloride, which have the same carbon base as the plastics. Colour must be applied to the surface of metals, whereas it can be mixed in with plastics. Metals are more rigid than most plastics, while plastics are very light, with a specific gravity normally between 0·9 and 1·8. Most plastics do not readily conduct heat or electricity. Plastics soften slowly and can easily be shaped while they are soft.

It is their plasticity at certain temperatures which gives plastics their main advantage over many other materials. It permits the large-scale production of moulded articles, such as containers, at an economic unit cost, where other materials require laborious and often costly processes involving cutting, shaping, machining, assembly and decoration.

Plastics not only replace other materials. Their properties can be exploited for entirely new applications. For example, plastic heart valves and other human 'spare parts' have made possible many recent developments in surgery.

There is no single plastics material which is suitable for all applications. It is important that the most suitable plastics should be chosen, and if necessary adapted, for each particular requirement. It is also important that the properties of the plastics material chosen should be exploited to the best advantage.

A plastics article may need to differ in design and appearance from a similar article made from another material such as metal or wood. This is due not only to the properties of plastics but also to the techniques employed in fabricating plastics products. These techniques include injection moulding, blow moulding, compression moulding, extrusion and vacuum forming.

Types of Plastics

There are two main groups of plastics: thermosetting materials and thermoplastic materials.

Thermosetting materials can be heated and shaped only once. Thereafter they are rigid and can be broken, but they cannot be softened again by heat without decomposing them. Urea-formaldehyde or UF, a resin obtained from urea ($NH_2CO{\cdot}NH_2$) and formaldehyde (CH_2O), and the similar melamine-formaldehyde or MF, from melamine ($C_3H_6N_6$) and formaldehyde, are two of the most widely used thermosets. Their toughness and high electrical and thermal resistance make them ideal for electric light switches and plugs, and for the handles of irons, kettles, pans, etc., while they are also used to impregnate laminated paper sheets from which heat- and scratch-resistant surfaces are made. Where dark colours are acceptable, the cheaper phenolic material, phenol-formaldehyde or PF, is often used.

Thermoplastic materials can be shaped and re-shaped as many times as required. If the temperature is not too high, they soften again without decomposing. Polyethylene (or polythene, as it is generally known) produced by the polymerization of ethylene ($CH_2{=}CH_2$) is still the most widely used thermoplastic. It is cheap to produce, tough and light (Specific Gravity 0·92 to 0·96).

Low-density polythene is used for making transparent sheet or film, cable and flex covering and flexible bottles, while more rigid bottles and containers are made from high-density polythene. The more recently developed polypropylene, from propylene (CH_3–CH–CH_2) has replaced polythene for many applications, since it is more resilient, less inclined to stress-cracking and is not weakened by flexing. However, it is more costly than several other similar plastics and tends to be brittle at very low temperatures. It is used to make a variety of products, including hinges, vehicle-engine radiator fans and moulded chair seats. Polystyrene, obtained by reacting benzene with ethylene, is an extremely cheap, light, rigid material, which is brittle and is often toughened by the addition of rubber. It is used especially for making toys and small rigid containers, where low cost may be more important than durability. Expanded polystyrene is an extremely light, rigid foam (Specific Gravity about 0·015) produced in blocks or by moulding for insulating and packaging. Polyvinylchloride or PVC, from vinyl chloride (CH_2=CHCl) can be produced in many forms to make, for example, rigid refrigerator linings, rigid and flexible pipes, furniture coverings and floor tiles. Unsupported PVC and PVC-coated fabrics are used to make bags, cases and clothing. PVC is a relatively heavy plastics (Specific Gravity 1·2 to 1·5). Nylon, a generic name for the polyamide thermoplastics, has different properties depending on the relative lengths of the $-CH_2-$ groups in the polymer. Nylon was the first synthetic plastics fibre to be introduced into the clothing industry, but it is also used wherever its great tensile strength or thermal resistance are needed, for example to make ropes, bristles and gearwheels. Polytetrafluoroethylene or PTFE is made from fluoroethylene, a compound of carbon and fluorine. Although it is difficult and costly to process, it is extremely resistant to chemicals and weathering, has very high temperature resistance and has low frictional properties. Apart from industrial uses, it provides the coating for non-stick cooking utensils.

Word Study

(1) USEFUL WORDS

plastic—permanently deformable by stress
elastic—temporarily deformable by stress

All bodies are strained by stress: if the strain disappears after the stress is removed, the body is *elastic*; if the strain remains after the stress is removed, the body is *plastic*.

For an *elastic* material, Hooke's Law states that the ratio of strain to stress is constant. The constant is the coefficient of *elasticity* of the material for the particular type of stress.

Some materials, such as rubber, which are not normally *plastic*, can be *plasticized* by mixing them with substances called *plasticizers*.

Thermoplastic materials do not lose their *plasticity*. They can be heated and shaped as many times as required.

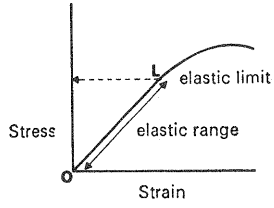


Fig. 2 — Graph on elasticity

A modern synthetic polymer is distinguished from other plastic materials by being called a *plastics* material, not a *plastic* material.

Synthetic polymers such as PVC and polyethylene are called *plastics* materials; they are *plastic* only when heated.

Polyethylene is a *plastics* which is produced by polymerizing ethylene gas.

to synthesize—to build from components

to analyse—to identify or measure components

In the presence of sunlight, plants *synthesize* carbohydrates from carbon dioxide and water in a process known as *photosynthesis.*

Rubber was known only as a natural product until its *synthesis* was achieved in 1916. *Synthetic* rubber is now manufactured for a number of applications.

When the substance was *analysed*, it was found to be composed wholly of carbon, hydrogen and chlorine.

Analysis of the material by analytical chemists showed that it contained magnesium oxide.

to apply—to put into position, to put into use

This adhesive must be *applied* to both surfaces which are to be bonded together.

The adhesive must not be allowed to dry after *application.*

Applying the law that action and reaction are equal and opposite, we see that the forces acting on a loaded beam are similar to the forces *applied* in breaking a stick.

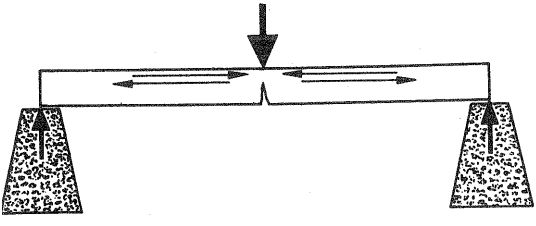


Fig. 3
Forces acting on loaded beam

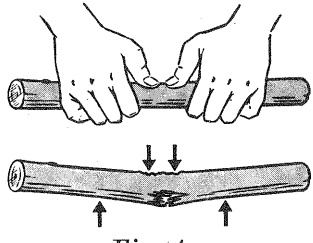


Fig. 4
Forces applied in breaking a stick

Newton's third law of motion is *applicable* to this example.

For cheap, flexible containers, polyethylene is generally suitable but for some *applications* polypropylene has advantages.

Other useful words (see vocabulary at end of book):

catalyst	to insulate
to corrode	to laminate
to design	to package
to dissolve	to react
to extrude	to resist
to form	specific
granule	to stabilize
to impregnate	

(2) WHAT THINGS ARE MADE OF, HOW THINGS PERFORM OR BEHAVE

The question 'What are things made of?' is answered differently by different kinds of scientist. The chemist thinks of chemical elements and chemical compounds. The biologist thinks of the basic elements of living matter—the cell and its nucleus—together with the biochemical compounds that are active in living plants and animals. The more practical scientist or engineer thinks of the components, for example of a radio receiver, that together constitute instruments and machines—the 'things' of his particular field. The technologist often has to think of the materials of which products or articles are made.

These different interests are reflected in the frequent use of particular words in the various fields of science and technology:

element	material
compound	structure
mixture	component
substance	

Air is a *mixture* of the gaseous *elements* nitrogen (N) and oxygen (O), of gaseous *compounds* such as carbon dioxide (CO_2), and of water vapour.

Non-gaseous *substances* which occur naturally as pure elements, such as gold (Au), are rare and are often highly valued.

Viruses have a crystalline rather than a cellular *structure*.

The engine has more than 300 *components*, made of a number of different *materials*.

In the same way, different kinds of scientists and engineers are interested in different attributes of the substances, objects or animals in their particular fields:

property	tendency
characteristic	performance
feature	behaviour

The physical *properties* of polyethylene include low specific gravity (S.G. 0·92 to 0·96) and low tensile strength (120–250 kg/cm^2 at 23°C).
One of the *characteristics* of this plastics material is its *tendency* to become discoloured with age.
This aircraft has several interesting *features*.
Not all details of this aircraft's *performance* are available. But it is known to have a long range even at very high speeds.

Here are some of the properties of plastics mentioned in this chapter:

rigidity flexibility brittleness

Polystyrene is a *rigid* material. Its *rigidity* can be a disadvantage since it is also *brittle*. The *brittleness* of polystyrene can be decreased by the addition of rubber, to make it *flexible*. But the natural *flexibility* of many other plastics makes them preferable for certain uses, particularly for articles which must withstand frequent *flexing*. For example, the covering for the wire *flexes* of electrical goods is generally made of polyethylene or PVC.
Notice that a flexible cord is called *a flex*.

(3) PREFIXES

A number of technical terms in this chapter have been formed by adding a **prefix** to an existing word or word root (e.g. form, **de**form; organic, **in**organic; plastic, **thermo**plastic). Prefixes are important in the making of new technical vocabularies and in the extension of existing ones. Prefixes are most often added to words or roots of Greek or Latin origin so that most prefixes are themselves Greek or Latin. Such prefixes may also be put in front of English words. Occasionally a Greek prefix is found in front of a Latin word or vice versa (e.g. *television* formed from *tele*—at a distance, from Greek, and *vision*—vision, from Latin).

mono—single

monochrome
monolayer
monomer
monomorphic
monoplane
monorail
monoxide

poly—many

polycentric
polycyclic
polygon
polyhedron
polymer
polypeptide
polyvalent

Notice that most polymers have a *poly-* prefix, for example:

polyamide
polybutadiene
polyester
polyethylene
polypropylene
polystyrene
polytetrafluoroethylene
polyurethane
polyvinylchloride

thermo-/thermo concerning heat

thermionic
thermocouple
thermodynamic
thermometer
thermoplastic
thermoscopic
thermosetting
thermostat

Here the prefix is related to the adjective *thermal*—thermal, and the technical term *therm*—therm, a unit of heat measurement.

2. Steel

Giles Newton and his wife, Susan, are visiting a steelworks. Mr. Argyll, a metallurgist, is about to show them a new process for making steel. Giles has to write an article about it.

SUSAN NEWTON **H'm. I'm not very impressed. I thought I'd see miles of railway tracks with trains chugging around carrying huge lumps of steel and big ladles of hot, molten metal. There's none of that here.**

GILES NEWTON **I'm afraid that's my fault, Mr. Argyll. I forgot to tell her we were coming to see an entirely new steelmaking process.**

MR. ARGYLL **Yes. It's a method of continuous steelmaking by the newly developed spray process. I presume, Mr. Newton, that you've seen one of the conventional steelworks?**

GILES **Yes, I have, and, of course, they have just what Susan expected: huge blast furnaces, converters, steel ingots, billet mills, plate and section mills, miles of railway track. All quite vast, and, naturally, stretching over huge areas of countryside.**

MR. ARGYLL **And, altogether, worth about one hundred million pounds. The steel refining equipment alone might cost twenty million pounds. But this new process has changed much of that.**

SUSAN **Including the cost?**

MR. ARGYLL **The capital cost of the actual steelmaking equipment here was only about one million pounds.**

GILES **So a really cheap process like this could revolutionize the steel industry?**

SUSAN **Oh?**

MR. ARGYLL **Well, perhaps we should go back to the beginning, Mrs. Newton. It all starts with iron ore, from which iron is extracted in blast furnaces.**

SUSAN **Blast furnaces. That's one out there, isn't it?**

MR. ARGYLL **Yes. Let me open the window a moment, and you can hear it for yourself.**

(*The sound of the blast furnace is heard through the window*)

Noisy, isn't it? We get used to it. Well, briefly, the blast furnace operation removes some impurities from the ore, and produces pig* iron.

GILES Susan, I'll bet you don't know why they call it pig iron.

SUSAN Of course I do. I've been reading it up. Pig is the name given to the mould in which the iron used to be cast.

MR. ARGYLL Very good, Mrs. Newton. The semi-purified molten iron that comes out of the blast furnace is also called pig iron, even though most of the production is not cast into blocks nowadays.

SUSAN You were going to tell me about this new system of continuous . . . what is it called?

GILES Continuous spray steelmaking.

MR. ARGYLL Ordinarily, in a conventional steelworks, steel is produced in a number of separate batches.

SUSAN So how does this new method overcome that?

MR. ARGYLL Well, in this process, the molten pig iron passes continuously from a tundish† to pour down through a ring of oxygen jets which atomize it into tiny droplets, each about a millimetre in diameter.

SUSAN Is that all?

MR. ARGYLL Various chemicals are then injected to combine with unwanted impurities which are not burned out by the oxygen.

SUSAN What happens to the impurities?

MR. ARGYLL Some come off in the form of gases, others collect as slag.

SUSAN Doesn't that mix with the steel?

MR. ARGYLL No. The slag is lighter than the steel, so that it floats on top and is tapped off at a higher level.

SUSAN Then what happens to the steel?

GILES It drops down into the receiving ladle, where a percentage of pre-heated scrap is added.

SUSAN But it doesn't stay there. Or does it?

MR. ARGYLL Oh, no. No, it's tapped continuously from the base of the receiving ladle. The steel is then ready to be cast into different shapes and sizes.

SUSAN How big is the equipment for spray steelmaking?

MR. ARGYLL Look through the window, near the big blast furnace.

SUSAN That little thing!

* *pig:* so called from the layout of the small moulds in relation to the main flow, resembling a sow with piglets.

† *tundish:* a container with a nozzle at the base.

MR. ARGYLL **That little thing can produce about one hundred and fifty thousand tons of steel every year, to whatever specification is required. That's as much as the output of a costly converter, thirty feet high.**

SUSAN **But it's only about five or six feet deep, and looks like an over-sized teapot.**

GILES **Well, that over-sized teapot, as you call it, makes instant steel. Molten pig iron and pre-heated scrap goes in at the top and, within seconds, high-grade steel comes out at the bottom.**

SUSAN **It's like making steel without a steel furnace.**

MR. ARGYLL **Not a bad analogy, Mrs. Newton. Now, if you're ready, we'll go out and see it in operation.**

In order to make steel, iron must first be extracted from iron ore by smelting in a blast furnace.

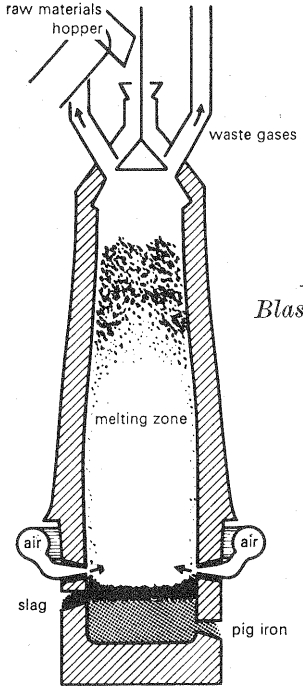


Fig. 1
Blast furnace

Making Iron

Charges of iron ore, coke and limestone are mixed in the correct proportions and are fed into the top of the blast furnace. Blasts of pre-heated air are blown into the charge from the base of the furnace and react with the charge as it descends. The coke burns to form carbon monoxide, which passes over the iron ore, reducing the iron oxides to metallic iron. The limestone absorbs impurities from the ore and forms a fluid slag which floats on the surface of the heavier molten iron.

The blast furnace is kept in continuous operation, and at intervals the iron and slag which have accumulated at the base of the furnace are run off separately.

Iron and Steel

The iron extracted from the blast furnace is known as pig iron. It contains a number of impurities, including carbon from the coke (see Table). It is very brittle and difficult to work. Pig iron is converted into steel by removing most but not all of the impurities. The presence of elements other than iron greatly affects the physical properties of steel.

Iron made from ore extracted in the United Kingdom might have the following analysis:

Carbon	4·0%
Silicon	1·2%
Phosphorus	0·13%
Manganese	0·5%
Sulphur	0·05%
Iron	94·12%

The carbon content of steel largely determines its usefulness for specific applications. As the carbon content decreases, the steel becomes less hard and more ductile and therefore more easy to shape. Low-carbon steels, with 0·06% to 0·12% of carbon, are known as mild steels and are the most widely produced nowadays. These mild steels are rolled into sheets or strips of various thicknesses to make car bodies, refrigerators, office cabinets, tin cans, etc.

A number of alloying elements can be added to steel in order to make it

suitable for specialized applications. For example, small percentages of nickel, chromium, manganese and vanadium are used to strengthen steels required for constructional work. Stainless steels contain about 12% of chromium, and steels for permanent magnets 30% of cobalt.

Making Steel

An efficient steelmaking process must be able to produce large quantities of high-quality steel as economically as possible, both in terms of capital costs for equipment and in terms of running costs for the process. It is also important to be able to control precisely the composition of the steel(s) produced. And it is necessary nowadays to consume large quantities of scrap steel in addition to pig iron in order to make new steel.

The L.D. Process

One modern steelmaking process is the L.D. process, developed about 15 years ago in the towns of Linz and Donawitz in Austria. This was one of the first processes to use pure oxygen to bring about the chemical changes needed to convert iron into steel.

The L.D. converter in which the steel is produced is a large steel vessel lined with heat-resistant bricks. Inside the converter oxygen is blown on to the surface of the charge through a water-cooled copper pipe, called a lance. The oxygen reacts vigorously with the impurities in the iron. Carbon is oxidized to carbon monoxide. Oxides of the other impurities combine with the limestone in the charge and float as slag on the surface of the metal. After about 20 minutes the 'blow' is stopped and the metal is sampled. More oxygen may be blown on to the charge until the composition of the metal is satisfactory. The steel is then tapped. The slag, which is above the level of the tapping hole, remains inside the converter and can be run off separately.

The steel is generally cast into huge blocks known as ingots, which are later cast or worked into slabs, strips, sheets or strands. Nowadays the steel is sometimes cast into its semi-finished form directly from its molten state.

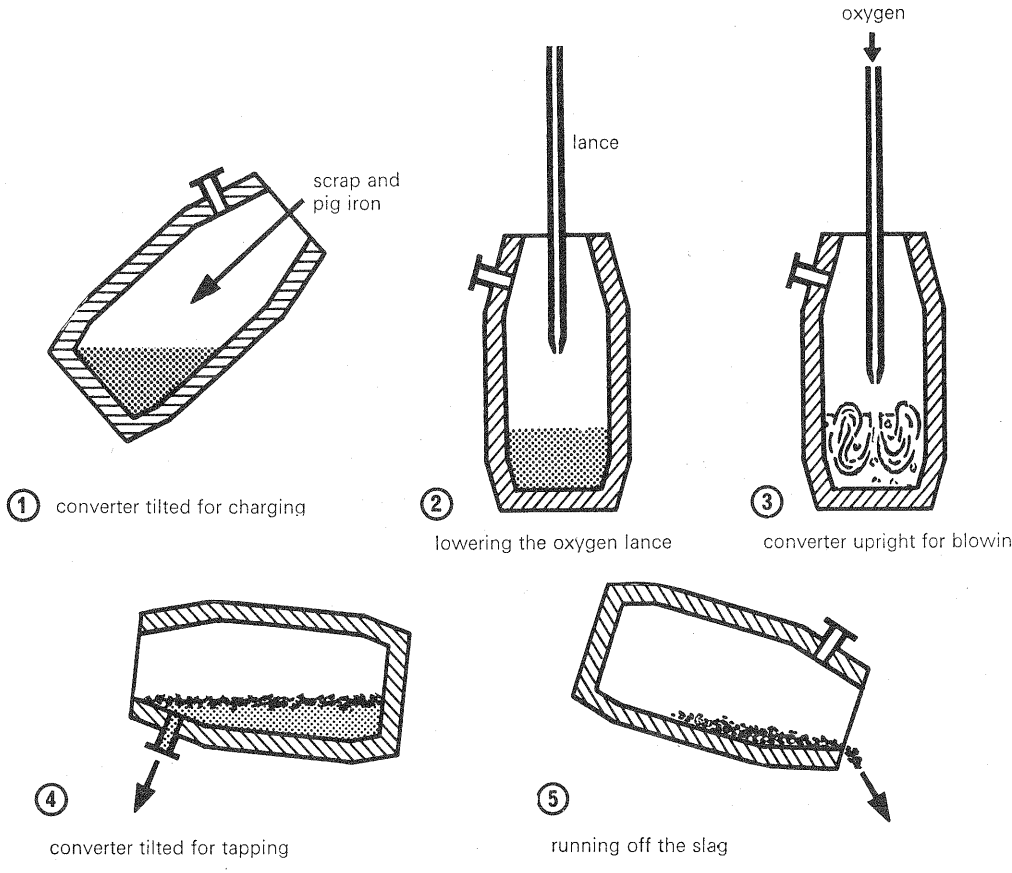


Fig. 2 — The L.D. process

Continuous Steelmaking

An obvious disadvantage of even the most up-to-date steelmaking processes is that they are intermittent. The steel is produced in a number of separate stages.

A continuous steelmaking process is now being developed. In this process, the molten pig iron is broken up into very small droplets by controlled jets of oxygen which are sprayed on to the descending metal. At this stage powdered limestone is also added. The droplets of iron react vigorously with the oxygen, and by the time they have passed through the reaction zone into a receiving ladle below, the iron has become steel. A slag forms on top of the steel and can be

drawn off separately. The steel itself is tapped continuously from the base of the receiving ladle. The process can consume large quantities of scrap which are fed into the receiving ladle and melted by the descending molten steel. The carbon content of the steel is controlled by adjusting the oxygen flow rate.

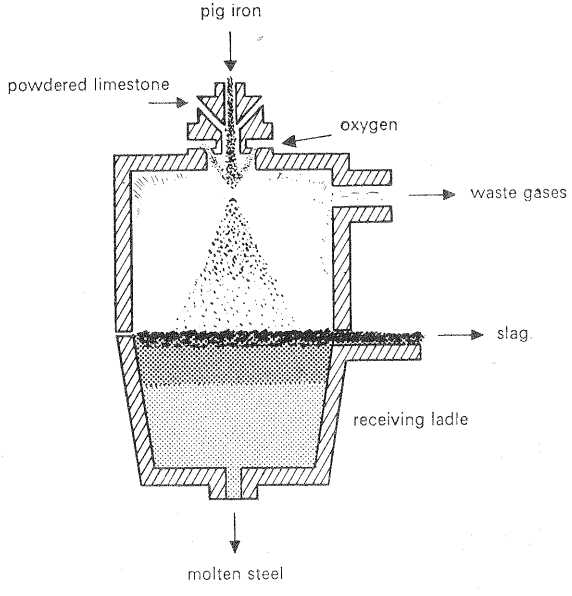


Fig. 3 — Continuous steel making

Continuous steelmaking does not require costly converters or equipment for handling pig iron. The molten iron may be taken straight from the blast furnace to be converted into steel, so that heat losses from the metal are minimal. Moreover, the molten steel can be fed directly to a continuous casting machine.

Word Study

(1) USEFUL WORDS

to extract—to take out, to draw out

Waste gases can be *extracted* from an industrial process by mechanical *extractors*. The *extraction* is often done by means of fans.

Notice that in metallurgy *to extract* means to take the pure metal out of its ores.

Iron is *extracted* from iron ore by heating the ore with coke and limestone. The *extraction* of aluminium is more complicated and is often performed electrically.

fluid—flowing

A *fluid* substance is any substance which flows. Thus water and steam are *fluids*. Both have *fluidity*.

liquid—neither gaseous nor solid

A substance is in its *liquid* state if it is neither gaseous nor solid. A gas can be *liquefied* if it is cooled sufficiently. For example, the *liquefaction* of the gas methane occurs at minus 160°C.

to melt—to liquefy by heat
to smelt—to extract iron from iron ore by melting the ore

At a certain temperature metals *melt*. They become *molten*. *Smelting* is the extraction of iron from iron ore by *melting* the iron ore. The ore is *smelted* in a blast furnace.

an oxide—a compound of oxygen and another element

A compound of oxygen and another element is called *an oxide*, for example carbon *monoxide* (CO). When an element is caused to combine with oxygen it is *oxidized*. *Oxidation* is extremely important in iron- and steelmaking.

pure—unmixed with other substances

A substance is *pure* if it is unmixed with other substances. *Impure* substances can be *purified*, and *purification* is regarded as complete when no trace of any *impurities* can be detected. In practice, it is difficult to *purify* any substance to 100% *purity*.

(2) SOME WORDS TO DESCRIBE CONTENT AND COMPOSITION

to contain—

Pig iron may *contain* 4% of carbon. Its carbon *content* is 4%.
When all the *contents* are removed from a *container* (for example, the liquids from a vessel), the *container* is empty.

to consist of—

Carbon dioxide (CO_2) *consists of* carbon and oxygen.

to be composed of—

Steel is *composed of* iron and a number of other elements. Its *composition* can be varied to suit different uses.

A number of signals can be joined into a *composite* signal which can be transmitted and then *decomposed* into its several *components*.

to constitute—

Steel *constitutes* the most important material used in the construction of large ships.

Iron and carbon are the main *constituents* of mild steel.
Dried foods can be *reconstituted* by soaking them in water.

(3) COST

capital cost
initial cost
running cost
overhead costs
unit cost

The *capital cost* of this steel-rolling plant was £25,000,000.

Though the *running costs* of this process are £1,000 per hour we must not forget also to add to the *total costs* the *initial cost* of heating the steel which is then rolled.

Because of the *overhead costs* we must run the plant continuously as far as possible in order to maximize output and so reduce *unit costs*.

(4) PREFIXES

e-/ex—out of

to eject
to emanate
to evaporate
to evolve
to exclude
to exploit
to extend
to extract
to extrude

im-/in—into

to immerse
impact
to impel
to impinge
to impose
to impregnate
to induce
to inject
inlet
to install
to insert
to involve

re—again, back

to re-align
to re-connect
to re-enter
to re-heat
to re-process
to retract

Notice the difference between the following pairs of words:

to re-count	to recount
to re-cover	to recover
to re-form	to reform

(5) SUFFIXES

A number of technical terms are formed by adding a *suffix* to an existing word or word root.

e.g. *-ic*

metal—metallic
atom—atomic
magnet—magnetic
electron—electronic

-ar

nucleus—nuclear
line—linear

-al

therm—thermal
electric—electrical
construction—constructional

-ity

saline—salinity
active—activity
stable—stability

-ivity

conduct—conductivity

-ation

saturate—saturation
rotate—rotation

3. Aircraft

At an airfield Giles Newton and his wife, Susan, have been watching a demonstration flight of a new short-haul jet aircraft. They're now talking to an expert, John Adams.

SUSAN NEWTON **There's something I don't understand. In the papers we read about the wonders of supersonic flights. We'll soon be crossing the Atlantic in little more than a couple of hours.**

JOHN ADAMS **Well, that's certainly coming.**

SUSAN **Then why all this emphasis on—what is it you call it?**

GILES NEWTON **Short-haul jets. You see, Susan, not everybody wants to fly across oceans and continents.**

JOHN **Yes, Mrs. Newton, you know that more than half the people who fly travel short distances, say a hundred to eight hundred miles. In fact, one airline, using our short-haul jets, do average sectors of a hundred and seventy one miles and their longest flight takes less than an hour!**

SUSAN **But why can't they use the older aircraft?**

GILES **She means propeller-driven, like piston-engined and the turbo-props.**

JOHN **That's what they've been doing. Usually second-hand aircraft from the long-haul airlines. But they're old, and they need a lot of servicing and the cost of running them per passenger mile is increasing all the time.**

GILES **Which means less profit.**

SUSAN **But these new jets must cost a lot of money.**

JOHN **Initially, yes. But not in the long run. You see, they're tailor-made for economy on short-haul.**

SUSAN **That sounds good, Captain Adams. But let's be specific.**

JOHN **Well, the long-haul jets make their money by the number of flying hours they achieve. Short-haul jets are engineered to profit by the number of landings they can make in the course of a day.**

GILES **I can understand that. The more often they land, the more passengers they can carry over short distances.**

SUSAN You said the short-haul jets are engineered specifically for the job. Can you explain that?

GILES I suppose the first thing is the ease of servicing.

JOHN Exactly. They require a minimum of ground service.

SUSAN Yes, but you still have to do all the same things: off-load passengers and cargo, refuel and all that sort of thing.

JOHN Right, but we do it on a different principle, much faster. Take fuelling, for example. There are three tanks, one in each wing and one in the middle. They're all inter-connected, and they're all filled from one point. And it takes less than ten minutes.

SUSAN It seems to me the longest time required is loading and unloading passengers, including bringing up the steps.

JOHN We have two systems, both self-contained. There are forward passenger steps on the left-hand side and a ventral stairway at the rear.

GILES But it takes time to put them into position.

JOHN Sorry, you're wrong again. That's one of the uses of the A.P.U.

SUSAN What's that?

JOHN It's a third engine—the Auxiliary Power Unit, or A.P.U. for short. Among other things it eases out the forward steps from under the floor and drops the rear ventral stairway.

GILES You said among other things. What else does it do?

JOHN When the aircraft's on the ground, and the main engines shut off, it provides air-conditioning for the passengers who stay on board during the six to ten minute stop-over.

GILES So you don't need a big air-conditioning van.

JOHN Exactly. The A.P.U.'s a very useful piece of equipment.

SUSAN Where's it located?

JOHN It's mounted in the fuselage tailcone. It's started by a press-button from the cockpit and runs off the main fuel supply.

GILES Does it do anything else?

JOHN Yes, it keeps the electrical system in operation while on the ground.

GILES Eliminating further ground equipment. How about power to start the main engines?

JOHN Yes, it does that as well. More saving of time and money.

SUSAN Baggage! Now that's something that seems to take for ever!

JOHN Well, most short-haul passengers have little baggage, so we provide carry-on luggage space at both front and rear entrances.

GILES **Cargo handling usually takes time and expensive equipment.**

JOHN **Not with our short-haul jets. We have two cargo holds, one forward, one rear, and they open at waist-high level, so that on-loading and off-loading can be done by one or two men actually standing on the ground.**

SUSAN **You always hear about planes being delayed because of technical faults.**

JOHN **That can never be avoided entirely.**

GILES **But I presume you've made provision for fast servicing of such faults.**

JOHN **Yes, most of the servicing and maintenance can be done from ground level.**

GILES **Another cutting down of costs. No gantries or scaffolding, and speedier operation, of course.**

JOHN **Yes, that's the theory. And I must say it works.**

How an Aircraft Flies

If an aircraft is standing on the ground, the air pressure on all its different parts is the same. This air pressure is increased or reduced when the aircraft moves.

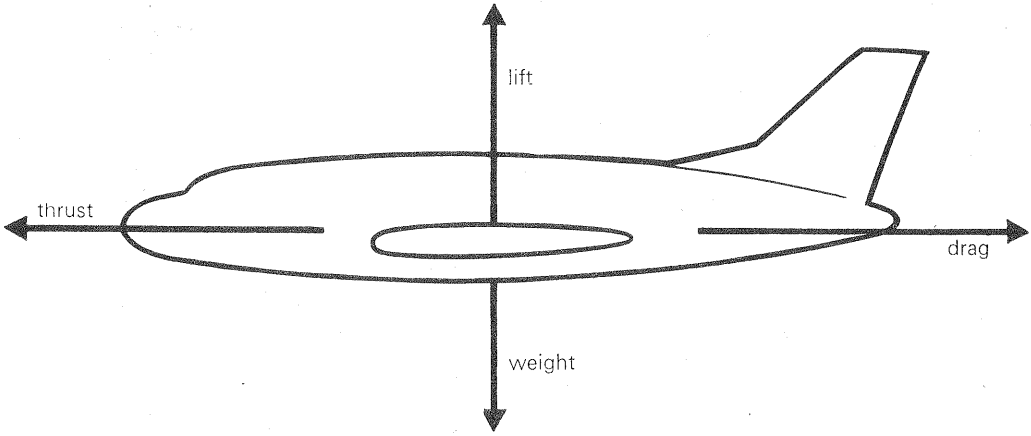


Fig. 1 — Diagram of aircraft

There are four forces which act on an aircraft as it flies through the air. The weight of the aircraft, due to the earth's gravitation, tends to pull the aircraft downward. Drag hinders the forward motion of the aircraft. Drag is caused by the resistance the airframe offers as it moves through the air and by the eddies of air which form near edges of the lifting surfaces of the aircraft. Weight and drag are overcome by thrust and lift. Thrust is provided by the engines which drive the aircraft forward. As the aircraft moves forward, the air flowing over the wings produces lift to raise the aircraft off the ground, and keep it in the air.

The upper surface of an aircraft wing is cambered (curved upwards) at the leading edge and the under surface is almost flat to give the highest lift/drag ratio. A rounded nose, smoothly curved top and a sharp tail is known as an aerofoil shape. This particular shape makes air flow faster and farther over the wing than under it. Pressure above the wing is reduced and the wing is given lift. The amount of lift increases with the speed of the aircraft.

Some Types of Civil Aircraft

LONG-RANGE JET AIRLINERS

A typical inter-continental jet airliner is designed to carry 150 passengers over five thousand kilometres at speeds approaching one thousand kilometres per hour in level flight. It has a good aerodynamic streamlined form and four jet engines which provide a combined thrust of seventy thousand pounds. The engines are in pods below the wings. Such an aircraft has high take-off and landing speeds and can therefore operate only between airports with long runways.

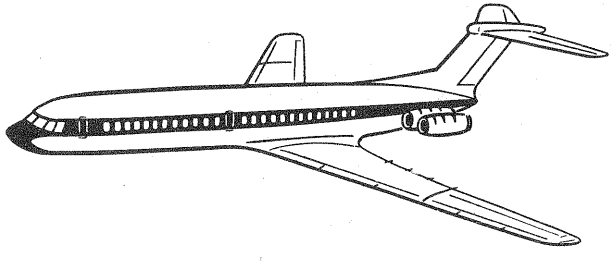


Fig. 2 — Long-range jet airliner

SHORT-HAUL JET AIRLINERS

Many airline routes have stages of less than one thousand, five hundred kilometres and smaller jet airliners have been designed specifically for such 'short-haul' operations. These aircraft are nearly as fast as the larger jet airliners, but carry only about eighty passengers. The engines are sometimes located beneath a high tailplane. This reduces noise in the passenger cabin. Short-haul airliners should be able to operate from relatively short runways and to permit rapid turn around (i.e. servicing, refuelling and exchange of passengers between flights).

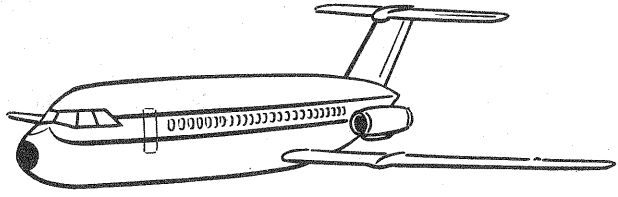


Fig. 3 — Short-haul jet airliner

LIGHT AIRLINERS

While most airliners continue to increase in size and speed, there is a growing need for aircraft which can operate from very small airfields on routes where there are seldom enough passengers to make the use of a standard airliner commercially profitable. Aircraft suitable for these conditions must be cheap and simple to build, to operate and to maintain. Such aircraft may carry only eight or nine passengers and will be powered by piston-engines. They may even have such normally outdated features as a fixed, rather than a retractable, undercarriage.

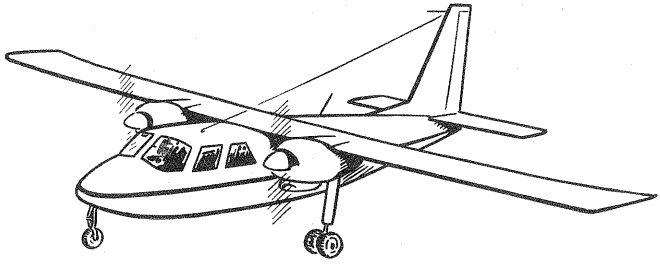


Fig. 4 — Light passenger aircraft

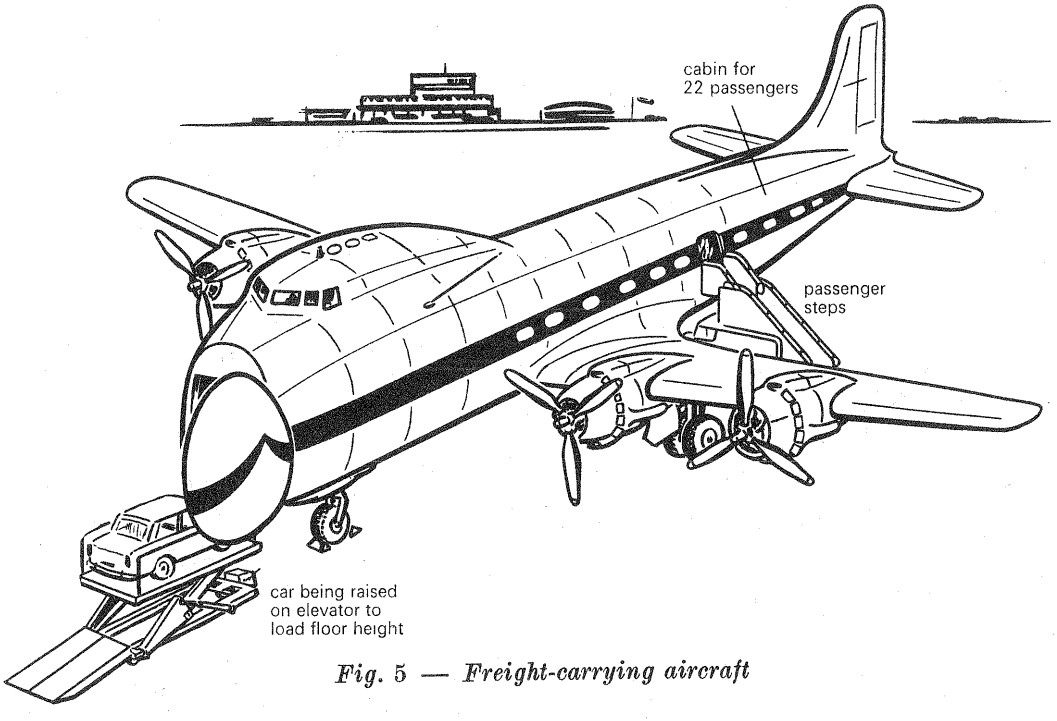


Fig. 5 — Freight-carrying aircraft

FREIGHT-CARRYING AIRCRAFT

Some aircraft are designed to carry bulky freight or vehicles. Easy access must be provided for loading and unloading, often at both the nose and the rear of the fuselage. Because freight-carrying aircraft do not need to fly at high speeds, they are normally powered by piston-engines or turbo-prop engines.

AIRLINERS OF THE FUTURE

The trend towards faster and larger airliners continues. Airliners in service at present cannot fly faster than the speed of sound (Mach 1). The first jet airliners capable of supersonic speeds will carry more than one hundred passengers at two thousand, two hundred kilometres per hour (Mach 2·2). This is the maximum speed attainable by aircraft with airframes made of conventional light alloys. Above Mach 2·2 the heat generated is so great that steel must be used. Airliners with airframes made of steel are being designed. They will fly at Mach 3 or more. The streamlined nose sections of supersonic airliners will be 'dipped'

during landing and take-off to provide better visibility for the pilot. Another innovation will be the use of 'variable geometry', whereby the wings will have two positions. The forward position will give maximum lift close to the ground while the rear position will give the best configuration for supersonic flight.

At the same time, there are designs for jet airliners carrying up to four hundred passengers. These huge aircraft will give rise to awkward problems of dealing with their large numbers of passengers at the airports from which they operate.

HELICOPTERS

The helicopter has one or more horizontal rotors which rotate around a vertical axis to provide not only lift but also thrust and directional control by means of the variable pitch of the rotor blades. A small vertical propeller at the tail of the helicopter counteracts the torque or tendency of the helicopter to turn in the same direction as the main rotor.

The helicopter is slow, noisy and uneconomical in horizontal flight. But its ability to rise vertically and to remain motionless in the air enable it to operate in difficult or confined conditions such as swamps, jungles and mountainous country and from the decks of ships at sea or small platforms on land. It is therefore ideal for rescue work, for surveying and for crop-spraying. Large helicopters are also being increasingly used as flying cranes for transporting heavy equipment.

Aircraft Engines

PISTON-ENGINES

Piston-engines, which drive propellers, use comparatively little fuel and are relatively efficient at low speeds and at altitudes of less than seven thousand metres. However, piston-engined aircraft cannot attain speeds in excess of about eight hundred kilometres per hour.

TURBO-JET ENGINES

Turbo-jet engines, or 'pure' jet engines, perform most economically at high cruising speeds and at altitudes of seven thousand metres or more. Near the

ground there is considerable loss of performance and fuel consumption rises to uneconomical proportions.

TURBO-PROP ENGINES

Turbo-prop engines, in which the turbines drive propellers, combine some of the advantages of both piston and pure jet engines. Speeds of up to seven hundred kilometres per hour at operating heights of about six thousand metres are attained economically and landing and take-off performance is good.

Word Study

(1) USEFUL WORDS

operate
operation
in operation
operational
operative

It can *operate* only between airports with long runways.

increase (*noun*)
increase (*verb*)
decrease

The air pressure is *increased* or *decreased* when the aircraft moves.

reduce
reduction

Pressure above the wing is *reduced.*

act
act as
act on
active
activity
activate

There are four forces which *act on* an aircraft as it flies through the air.

design—work out in detail

We have to *design* a short-haul aircraft for carrying freight.

The *design* of the new aircraft has just been started.

The *design* data will depend on tests of a new light alloy.

The *designers* have been asked to make several modifications to their original *design.*

to design
design
design data (*plural*)
designer

designate—name

The new aircraft type is *designated* 'SH 603', but its commercial name will be 'Pegasus'.

The *designation* of the new aircraft type will be 'SH 603'.

to designate
designation

modify—change slightly
specify—state item by item

It is not too late to *modify* the shape of the tail fin to reduce drag.

Two *modifications* to the undercarriage have now been *specified.*

The complete *specification* must be drawn up by the end of this month.

The presence of an invading virus generates *specific* antibodies.

Every component of an aircraft has a *specifiable* function to perform.

to modify
to specify
specification
modification
a specific antibody
a specifiable function

behave—act in a natural way
perform—act in a controlled way

The aircraft *behaved* well on its first test flight. It was immediately responsive to all the controls, all the specified tests were *performed* and repeated without trouble, and no unexpected faults were observed.

The learning *behaviour* of the white mice was studied by placing them in a complex maze and observing the number of trials they required to find the exit and the food without making any mistake. Once they had succeeded, subsequent trials tended to become confident *performances* of a routine carried out at high speed.

The department of *behavioural* sciences is making a special study of aggressive *behaviour* in animals and in man.

The new engines have now *performed* reliably for 2,000 hours. Aircraft A has a better *performance* than aircraft B: its cruising speed is 50 km/hr higher and its range is 120 km longer for the full load of fuel.

to behave
behaviour
a behavioural science
to perform
performance

compare—consider similarities and differences
contrast—consider differences

Compared with propeller-driven aircraft, jet aircraft have higher landing and take-off speeds and therefore need longer runways.

A *comparison* of Type A with Type B shows that Type A has more advantages for our purpose.

By comparison, Type A has the advantage of higher crusing speed and Type B the advantage of greater comfort.

In comparison with designers of propeller-driven aircraft, designers of jet aircraft have greater freedom in deciding where to place their engines.

The fuel consumption of a light petrol-engined two-seater aircraft is *comparable with* that of a sports car.

The huge bulk of the freight carrier *contrasts with* the slim streamlined form of the fast jet airliner.

The orange-yellow colour in which this aircraft is painted is intended to make as great a *contrast* as possible with the blue-grey sky background against which it operates so that it is clearly visible to other aircraft in the vicinity.

The model of the new supersonic aircraft shows advanced aerodynamic design; *by contrast*, even the most modern aircraft look clumsy and slow.

to compare
comparison
by comparison
in comparison with

a comparable fuel consumption

to contrast with
contrast
by contrast

horizontal—parallel to the horizon, level
vertical—perpendicular to the horizon, upright

An ideal projectile is a particle which moves in a vacuum with constant *horizontal* velocity under the action of a constant *vertical* force.

A spirit-level shows the *horizontal.*

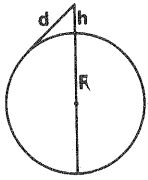


Fig. 6 — Distance of the horizon

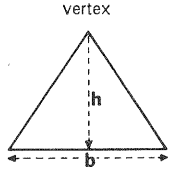


Fig. 7 Area of a triangle

A steady plumb-line shows the *vertical.*

Aircraft take off *horizontally*; helicopters take off *vertically.*

To an observer at elevation h above the surface of the Earth, the distance of the horizon is approximately $\sqrt{2hR}$, where R is the radius of the Earth.

The area of a triangle is $\frac{1}{2}bh$, where b is the length of the base and h is the height of the vertex above the base.

a horizontal velocity
horizontal
horizontally
horizon
a vertical force
vertical
vertically
vertex

obsolete—out of date

Supersonic aircraft will not make all subsonic aircraft *obsolete*: many jobs remain that only subsonic aircraft can do.

The development of aircraft design is now so rapid that by the time a new aircraft has been designed, tested and certified as airworthy it is already *obsolescent.*

The period of *obsolescence* varies from one aircraft type to another: in the case of a modern airliner, it is assumed that the aircraft will have become *obsolete* after eight years.

an obsolete aircraft
an obsolescent aircraft
obsolescence

4. Nuclear Power

The Newtons are going to meet a scientist who works at a nuclear power station. On the way, Susan asks Giles to clear up a few points that are puzzling her.

SUSAN NEWTON **I know we can get electricity from nuclear power. But how's it different from getting it from coal or oil?**

GILES NEWTON **Basically, Susan, there's no difference in the actual generation of electricity. Almost all our electricity is created by heating water to form high-pressure steam. And that passes through turbines geared to rotate generators that produce the actual electricity. This is fed into the National Grid where and when required.**

SUSAN **But what's the advantage of using nuclear power?**

GILES **That's something we'll find out now, because here we are.**
(They arrive at the Nuclear Power Station.)

MR. HARRISON **. . . and that's just the point. In an advanced reactor, as much electricity can be made from one ton of enriched uranium fuel as from 75,000 tons of coal.**

GILES **Then, Mr. Harrison, you need only a few lorry loads of fuel at a nuclear power station instead of many train loads of coal.**

MR. HARRISON **Exactly.**

SUSAN **So you don't need railway sidings and berths for colliers and barges.**

MR. HARRISON **No, we don't.**

GILES **With coal you have a residue of ash. What about the used fuel from a nuclear-powered station?**

MR. HARRISON **Well, being radioactive, it can't be left lying around.**

SUSAN **So how do you dispose of it?**

MR. HARRISON **It's loaded into thick steel flasks each weighing forty-five tons. They're despatched to the United Kingdom Atomic Energy Authority for reprocessing.**

GILES **So there's little actual wastage?**

MR. HARRISON **But that doesn't eliminate cost. The reprocessing isn't done for nothing.**

SUSAN **But electricity from a nuclear-powered station is cheaper than from a coal-fired plant, isn't it.**

MR. HARRISON **Well, the cost of operation of nuclear stations is only half the cost of even the least expensive coal-fired stations. And later on the figures will show an even greater advantage for nuclear energy.**

GILES **But don't nuclear stations cost more to build?**

MR. HARRISON **Yes, they do. But their cheaper running more than offsets this. The Advanced Gas Cooled Reactor, known as the A.G.R., is cheaper to operate than the earlier stations because of the use of improved fuel and better technology.**

SUSAN **And aren't the nuclear stations cleaner in operation?**

MR. HARRISON **Yes, and they're better looking than conventional stations and can be sited in places unsuitable for conventional plant. They don't have to be near railway lines or deep water channels. And they can be built nearer to centres of population than before, since restrictions on siting them were eased a year ago.**

SUSAN **And all this means cheaper electricity for the housewife. Won't the consumption of electricity go up?**

MR. HARRISON **Yes, it's going up at a little more than seven per cent per annum. An increase in consumer demand of at least this rate is being experienced in nearly all the well-developed countries.**

SUSAN **And what about the under-developed countries?**

MR. HARRISON **Well, in these countries the demand is increasing at a somewhat higher annual rate. This, of course, means more work for those industries that produce generating plants.**

GILES **That's an interesting point. Thank you very much, Mr. Harrison.**

Nuclear Power

The atom is the smallest particle of an element that can have a separate existence or take part in a chemical reaction. The atom was once thought to be an entity of homogeneous composition, incapable of being split into smaller fractions and

composed of unalterable substance characteristic of the particular element. But the atoms of every element are now known to be composite structures of three sub-atomic particles—the electron which carries a unit negative electrical charge, the proton which carries a unit positive electrical charge and the neutron which is electrically neutral. All atoms have a very small nucleus composed of the relatively massive protons and neutrons packed closely together. Around the nucleus there are shells of the relatively very light electrons. As electrons and protons carry equal but opposite electrical charges, the number of electrons in the shell of a normal atom is equal to the number of protons in the nucleus.

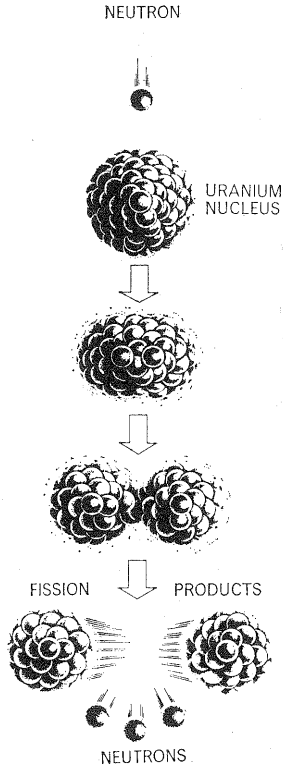


Fig. 1 — Neutrons

All the 100 or more chemical elements now known are built up of the same three sub-atomic particles. Each element is characterized by the number of protons in the nuclei of its atoms: thus hydrogen, the lightest element, has one

proton in its atoms; helium has two while uranium, one of the heaviest elements, has a nucleus of 92 protons together with a still larger number of neutrons. It should therefore be possible to change atoms of one element into atoms of other elements—the alchemists' dream—by bombarding them with suitable projectiles. The best projectiles for this purpose were found to be neutrons. Their mass enables them to pierce the shells of electrons and their small size and electrical neutrality enables them to penetrate the nucleus itself. Once inside the nucleus the intruding neutron may cause a restructuring of the arrangement of protons and neutrons without causing outward disturbance; in this case, the neutron is absorbed and an isotopic atom of the element is formed. But the intruding neutron may alternatively disrupt the heavy nucleus, causing it to disintegrate into two or more parts which then become the atoms of two or more different elements; a transmutation of an element has then occurred. When heavy atoms are split in this way some loss of mass occurs and this loss of mass is converted into an equivalent quantity of energy according to Einstein's law $e = mc^2$ where c is the velocity of light.

To put this kind of nuclear reaction to good use it is necessary to find sources and absorbers of neutrons and fissile material which together form a controllable system. The system has to be designed so that disintegrating nuclei generate just enough neutrons to maintain a steady succession of further disintegrations, to produce a controllable chain reaction. The energy released by the chain reaction is transformed into heat.

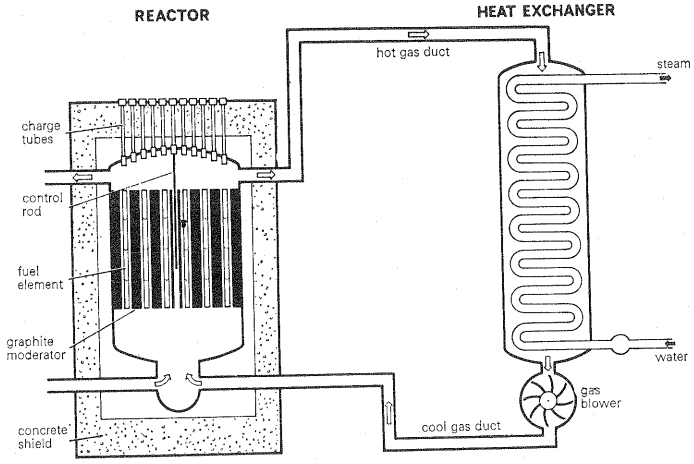


Fig. 2 — Reactor

A nuclear power reactor is a machine in which this chain reaction can be kept going at a steady, controlled rate so that it provides heat that will produce electricity. Most of a nuclear power station is exactly like any other power station. The only difference is that the heat is provided by uranium in a reactor, not by coal or oil or gas burned in a furnace.

For the chain reaction to continue at a steady rate the number of neutrons which carry on the reaction must be controlled. This is generally done by absorbing excess neutrons in boron, made up into control rods.

Usually it is most convenient if the escaping neutrons are slowed down so that they can more easily split the nuclei. The neutrons are slowed down by surrounding uranium fuel by a moderator (so called because it moderates the speed of the neutrons). This type of reactor uses graphite as the moderator. The whole assembly of fuel, moderator and control rods is called a nuclear reactor.

It is a new type of furnace in which heat is produced by splitting of uranium nuclei. Two more items are needed:

1. a concrete shield to prevent the escape of dangerous radiation;
2. a means of transferring the heat.

In the reactor at Calder Hall heat is transferred by circulating carbon dioxide gas. The hot gas is used to produce steam which will drive electricity generators. So the power of the atom can be used to produce electricity.

A.G.R.

New nuclear power stations now being built by the Generating Boards in Britain belong to a more sophisticated 'family' of the original Calder Hall-type reactor, called the Advanced Gas-cooled Reactor. Like the Calder Hall-type reactors it uses carbon dioxide gas as a coolant and graphite as a moderator. Its difference from the Calder Hall-type reactors is in the fuel. Instead of using 'natural' uranium, as in the earlier types, it uses 'enriched' uranium. The importance of this development is that it has achieved further reductions in the costs of electricity generation from nuclear power. Further changes in the type of fuel used are now being considered which could reduce the costs even further.

S.G.H.W.R.

Both the reactors described so far are gas-cooled. An alternative system has water-cooling. The newest type of nuclear power reactor built in the United Kingdom is called the Steam Generating Heavy Water Reactor. In this type of reactor the moderator is 'heavy' water, a chemical variant of ordinary (or 'light') water. It is more efficient than ordinary water for this purpose. Immersed in this moderator, the uranium fuel (in the form of rods contained in pressure tubes) gives off heat which boils ordinary water to provide steam that drives the electricity generators.

The S.G.H.W.R. has two great advantages over many other reactor designs:

(i) Although it is an advanced system, its design is based on well-established engineering and manufacturing techniques. Many key items can therefore be made off-site in the manufacturers' works.

(ii) Nuclear plants over a wide range of outputs can be designed simply by incorporating different numbers of pressure tubes of the standard design.

The long-term future of nuclear power lies with fast reactors. The best fuel for fast reactors is plutonium.

Both the A.G.R. and the S.G.H.W.R.—at the same time as producing electricity—turn part of the uranium into this new very rich nuclear fuel, called plutonium. To supply the necessary amount of plutonium for fast reactors, it will be necessary for some years to build new nuclear power stations of the A.G.R. or the S.G.H.W.R. type.

Fast Reactors

Plutonium fuel can be used in a very different type of reactor called a fast breeder reactor, which will come into commercial use during the late 1970s.

The economic importance of the fast breeder reactor can be seen from the following calculation:

1 ton of coal in a conventional power station will produce 2,400 units of electricity.

1 ton of uranium in an ordinary nuclear reactor will produce 480,000,000 units of electricity.

1 ton of uranium (converted to plutonium) and used in a fast breeder reactor will produce 18,000,000,000 units of electricity.

The fast breeder reactor is so called because the neutrons are not slowed down and because the nuclear fission in the reactor can 'breed' more plutonium fuel (in a 'blanket' of uranium which is placed round it) than is used up in the generation of heat.

The fast reactor at Dounreay in Scotland, which was the first of its kind in the world to supply electricity for public use, has produced more units of electricity than any other fast reactor in the world.

Britain is now building a second (250 megawatt) fast reactor which will establish the design for commercial stations of this type.

Word Study

(1) nucleus
nuclear
nuclear fission
fissile

Nuclear fission takes place when a free neutron strikes the *nucleus* of a *fissile* element such as uranium.

(2) react
reactor
reaction

The heavy fractions are vaporized and enter a *reactor* where . . .

Platinum is used as the catalyst in a *reaction* which takes place in a platformer.

A virus breaks down the carbohydrate constituents of the cell wall by enzymic *reaction.*

Ammonia *reacts* very readily with sulphuric acid to form ammonium sulphate.

As with the two-*reactor* station, all plant in the single *reactor* station is housed in one composite building.

A chain *reaction* is started. To slow down the nuclear fission, boron steel rods are dropped into the *reactor.*

Action and *reaction* are equal and opposite.

Each monomer molecule can be made to *react* with similar monomer molecules to form a chain. This *reaction* is known as polymerization.

The energy released by the nuclear *reaction* heats a stream of gas.

Urea is made by combining ammonia with carbon dioxide but this *reaction* occurs only . . .

(3) generate
generator

There is one turbo *generator* for each reactor.

The hot gas is blown over thousands of tubes of water, thus *generating* steam which drives ordinary turbine *generators.*

A nuclear reactor *generates* neutrons which react with the fissile materials of the core.

(4) condense
condenser
condensate

When steam impinges on a cold surface it *condenses* to form water.

A *condenser* is a device which exposes a large area of cold surface to any steam which enters it.

Distilled water is the *condensate* from steam.

(5) control (*verb*)
control (*noun used as adjective*)

The fission process is *controlled* at the desired level of activity by moving *control* rods.

(6) fuel
refuel

The boilers of conventional power stations have to be charged with oil or coal continuously, but nuclear power stations are *refuelled* only at long intervals.

5. Oil

Giles Newton, and his wife, Susan, are visiting their friend, John Lane, an oil company executive. He's answering their questions about oil.

JOHN LANE **You see, Giles, I'm on the management side of the business.**

GILES NEWTON **We only want a general background, John. And I know you've been to the oil wells and refineries.**

JOHN **Just about all over the world.**

SUSAN NEWTON **Then, please will you tell me the correct name for the stuff that actually comes out of the wells.**

GILES **She means crude oil.**

JOHN **That's petroleum.**

SUSAN **Oh! Those are the sort of answers I always get! Which is it? Petroleum, or crude oil?**

JOHN **Petroleum is crude oil, oil before it's refined. To be precise it's 'crude petroleum oil', and we call it crude for short.**

SUSAN **Oh! Oh, I see. This crude oil, this petroleum, what's it like?**

JOHN **It varies from one oilfield to another.**

GILES **Oh. Are there different kinds of petroleum?**

JOHN **Well, they're all mixtures of hydrocarbons. But no two oilfields ever deliver crude of exactly the same composition.**

SUSAN **John, I'll be quite happy with a general description: colour, for instance.**

JOHN **The colour ranges from yellow through green to black. The lighter its colour, the easier it is to pour. The liquids vary in density from thin and treacly to thick and viscous. Sometimes it may be too thick to pour at all.**

SUSAN **Oh, so it isn't always a liquid?**

JOHN **Oh no, not always. It can be gas or vapour.**

GILES **By the way, what exactly is bitumen?**

JOHN **Well, the type of bitumen usually found on the earth's surface is a residue of petroleum from which all the more volatile elements have long since evaporated. It's black or brown, solid, perhaps, or a very viscous non-crystalline liquid.**

GILES **The ancient Egyptians used bitumen, didn't they?**

JOHN Yes, five thousand years ago they used it as mortar, for waterproofing and even for road surfaces.

SUSAN Bitumen must be one of the things you get when you refine crude oil.

JOHN Yes. The first step in refining crude oil is fractionating by distillation. Look out of the window. Do you see those high columns?

GILES Yes.

SUSAN Oh yes, those towers.

JOHN They're distillation towers where we separate the oil into fractions. The crude oil is fed through a furnace into the bottom of the tower. We can't see inside the tower, so let me show you a diagram. Look, here.

SUSAN Oh, I see.

JOHN This fractionating results in six main raw materials.

GILES I suppose these go through further refining and processing?

JOHN Yes, and from this we derive hundreds of what you may call direct products.

GILES And also basic ingredients for the development of thousands more?

JOHN Yes. In the fractionating or distillation process, one of the six basic fractions is separated out as petrol, for use in cars, piston-engined aircraft and so on. This fraction is less than one-quarter of the crude oil that goes into the distillation tower.

GILES What about all the rest of it, more than three-quarters?

JOHN There's the gas that can be liquefied and bottled or piped into homes.

SUSAN For cooking and heating?

JOHN Right. There's the fraction called kerosine or paraffin.

GILES For lamps and heaters?

JOHN And for driving tractors.

SUSAN Also jet aircraft.

JOHN Yes, jet fuel is basically paraffin or kerosine, so is white spirit for paints—and also a great variety of insecticides. Do you want to hear more?

SUSAN Yes, please! It's fascinating.

GILES Doesn't another fraction of the crude oil produce diesel fuel for buses, trains and lorries?

JOHN Yes. And another fraction is 'de-waxed' to give us lubricating oils and greases for machinery of all kinds.

SUSAN **So they use everything. I'm sure they don't waste the wax.**

JOHN **No, it has a lot of uses—for candles, waxed paper and many types of polish. Oh, Susan, this will interest you. Those same waxes are used to make cosmetics.**

SUSAN **You mean the things I use for make-up? And the creams I rub into my skin?**

JOHN **Yes, even your nail varnish is based on a by-product of crude oil. And some of the fractions of crude go through a process called cracking and the results provide a starting point for the synthesis or organic chemicals that nature is unable to supply in sufficient quantities.**

GILES **I've read somewhere that oil-based chemicals are vital to the development of many plastics.**

JOHN **Yes, including Susan's nylon stockings, also the soapless detergents she uses, shampoos, your car tyres, photographic film . . .**

SUSAN **Please, John! Stop. My head's going round in circles.**

JOHN **All right, but I warned you it could take three weeks to tell you the whole story!**

Oil Wells

Petroleum oil is normally found in strata below the ground where it has been formed over millions of years from deposits of small plants and animals overlaid and compressed by sedimentary mud and rock. The oil, which may lie in a stratum of porous rock, is usually prevented from seeping up to the surface by impervious rock strata. It is necessary to drill through the rock and convey the oil to the surface by means of pipes.

Crude Oil

The crude petroleum oil obtained from wells consists of a mixture of hydrocarbons each of which is a chemical compound of carbon and hydrogen.

The simplest hydrocarbons are gases. The simplest of all is the gas methane, the molecule of which has one carbon atom and four hydrogen atoms. Methane

has a boiling point of −160°C. Hydrocarbons with from five to eighteen carbon atoms are liquid at normal pressure and temperature. For example, octanes, found in gasoline, have eight carbon atoms and boil between 106·5°C and 125·8°C, depending on the structure of the particular octane. Hydrocarbons with larger molecules have higher melting and boiling points than hydrocarbons with smaller molecules. The hydrocarbons with larger molecules, such as those found in paraffin wax, are normally solid or semi-solid at normal pressure and temperature. The heaviest molecules of all, with more than fifty carbon atoms, are found in bitumen. Thus the hydrocarbons in crude oil range from dissolved gases and light liquids to heavy oils and waxy solids. The proportions of the various hydrocarbons differ from one oilfield to another and the properties of each deposit of crude oil have to be determined and evaluated. Crude oil may also contain some impurities such as sulphur.

Oil Refineries

SEPARATION

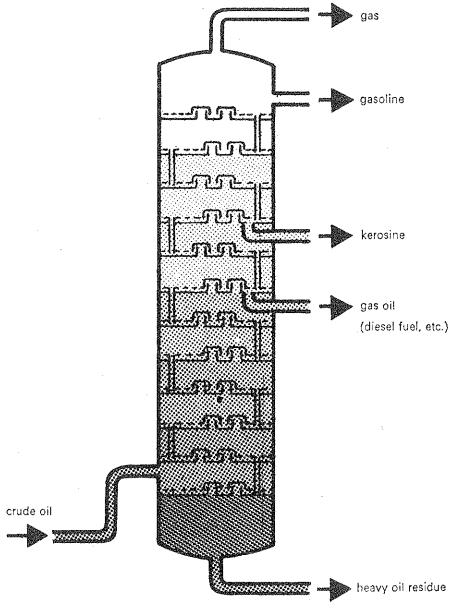


Fig. 1 — Distillation column

Because the different hydrocarbons present in crude oil have different boiling points, the crude oil can be heated and the hydrocarbons which are vaporized can be separated from those which remain as liquids. Thus separate fractions can be obtained. This is the principle of distillation which is used many times in the processing of oil at the refinery.

The crude oil is heated and passed through pipes into the distillation column where the fractions are separated. The heaviest hydrocarbons remain liquid and are drained off at the base of the column. As the vapours of the lighter hydrocarbons rise, they become cooler until they condense and can be drawn off as liquid fractions. Hydrocarbons with relatively few carbon atoms do not condense until they are near the top of the column. Finally, there are some hydrocarbons which remain as vapour even at the top of the column.

Primary distillation, which yields several fractions, is carried out in the main column of the crude distillation unit. Further distillation is carried out in subsidiary columns to separate some of the fractions still further.

The heaviest fraction obtained from primary distillation is re-distilled under reduced pressure in a vacuum distillation unit to produce waxes and lubricating oil.

CONVERSION

Distillation alone cannot yield oil products in the proportions in which they may be required. In some countries gasoline for petrol is the most important fraction, whereas in other countries fuel oil, for heating and for heavy industry, may also be important. Further processes convert some of the unwanted fractions into products for which there is a local demand.

Heavy fractions are converted into lighter fractions in a catalytic cracking

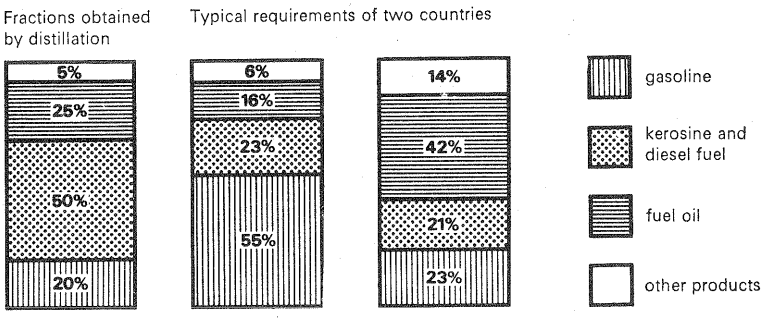


Fig. 2 — Oil requirements

unit. The heavy fractions are vaporized and enter a reactor where they are passed through a catalyst, a substance which accelerates reactions without changing itself. Inside the reactor the large molecules are cracked into smaller molecules. The cracked molecules are then separated in a distillation column which is part of the catalytic cracking unit.

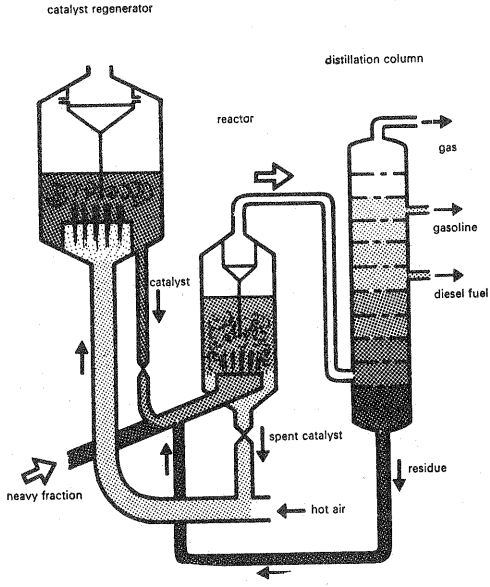


Fig. 3 — Catalytic cracking unit

Catalytic cracking yields gas, high-grade gasoline and diesel fuel. The catalyst, which is in the form of grains or of a powder, is blown back into the regenerator, where it is cleaned in order to be used again.

The gasoline obtained by distillation is by itself unsuitable for many modern engines. The quality of some of this gasoline is now improved by using platinum as a catalyst in a reaction which takes place under controlled conditions in a special unit called a platformer. The conversion process improves the low-grade gasoline by re-forming its molecules. Re-formed gasoline is generally blended with the desired proportions of low-grade gasoline and of high-grade gasoline obtained by catalytic cracking.

FINAL TREATMENT

The main products of crude oil may be given further treatment before they leave the refinery. They are purified by the removal of unwanted substances, such as sulphur, or treated by the addition of other substances which improve their performance for particular applications.

Some oil products are given special treatment at the refinery to provide the materials for the chemical industries which manufacture plastics, detergents, fertilizers and insecticides.

Word Study

(1) *vapour*—the gaseous state below the critical temperature
evaporate—convert from liquid to vapour

The amount of water *vapour* in the atmosphere is usually measured by a hygrometer.

At its boiling point a liquid has a *vapour* pressure equal to the external pressure.

Petrol *vaporizes* readily at normal temperatures.

The latent heat of *vaporization* of water is 537 calories per gram at 100°C and 76 cm pressure.

If pure water is *evaporated* to dryness, no residue remains.

The *evaporation* of water from reservoirs is reduced by allowing a thin film of oil to spread over the surface.

vapour
a vapour pressure
to vaporize
vaporization
to evaporate
evaporation

(2) *condense*—physical process—convert vapour to liquid or solid by cooling (*see also Nuclear Power*)

At normal pressures steam *condenses* at 100°C.

If air is cooled, the temperature at which *condensation* of water vapour first occurs is called the dew point.

The *condensate* obtained from a boiling mixture of water and alcohol also contains both water and alcohol.

A well-designed *condenser* exposes within a small volume a large area of cooled surface to the incoming vapour.

to condense
condensation
condensate
condenser

(3) *distil*—vaporize in one vessel and collect the condensate in a second vessel
Heavy oil fractions have to be *distilled* under reduced pressure.
Distilled water is tasteless and odourless.
Water and alcohol cannot be separated by *distillation.*
The process of *distillation* separates a liquid into a *distillate* and a residue.

to distil
distilled water
distillation
distillate

(4) *lubricate*—make run smoothly
Metal-to-metal surfaces are *lubricated* to reduce friction.
Lubricating oil reduces wear between metal surfaces by separating the surfaces.
Lubrication reduces noise and wear.
Oil is not the only common *lubricant*; graphite is also commonly used.

to lubricate
lubricating oil
lubrication
lubricant

(5) *proportion*—numerical relation of a part to the whole
ratio—numerical relation of one part to another part
Hydrogen and oxygen are present in water in the *proportions* of 1 to 8 by weight.
The areas of triangles standing on the same base are *proportional* to their heights.
The profits of the enterprise will be divided *proportionally* among the participants on the basis of the work each one does.
One gram of A reacts with three grams of B, and so on *proportionately.* For other quantities of A proportionate amounts of B are required.
Compared with the human adult, the new-born human baby has a *disproportionately* large head.

If A : B = C : D, the *ratio* of A to B equals the ratio of C to D.

If two maps of the same area have different scales in which distances are in the *ratio* of 1 : 5, then comparable areas are in the ratio of 1 : 25.

proportion
a proportional area
proportionally
a proportionate amount
proportionately
disproportionately
ratio
in the ratio of

(6) *catalyst*—a substance which increases the rate of a chemical reaction but which itself remains unchanged

In the presence of mercuric sulphate as *catalyst*, acetylene combines with water to form acetaldehyde:

$$C_2H_2 + H_2O \longrightarrow CH_3 \cdot CHO$$

The reaction in which ammonia mixed with oxygen is oxidized to nitric acid is *catalysed* by platinum wire grids.

Water has *catalytic* properties difficult to demonstrate because, in any chemical system, the last traces of water can be eliminated only after prolonged treatment.

Catalysis of a second degree, in which the activity of a catalyst is increased by a second substance, is also known.

catalyst
to catalyse
a catalytic property
catalysis

6. Civil Engineering

Giles Newton and Susan, with Richard Williams, who's a civil engineer, are looking at the suspension bridge over the River Severn.

SUSAN NEWTON **What a magnificent sight! Mr. Williams, that must be one of the longest bridges in the world!**

MR. WILLIAMS **Sorry to disappoint you, Mrs. Newton, but it's far from that! I know one that's about seventeen-and-a-half miles—and that's not even the longest.**

GILES NEWTON **Remember, Susan, we've driven on overhead roadways that run several miles. They're bridges, too, you know.**

SUSAN **Oh, yes. Well, it must hold some sort of record.**

MR. WILLIAMS **For the moment, yes, but, perhaps, not the way you mean. You know what type of bridge it is, of course.**

SUSAN **They talk of it as the Severn Suspension Bridge. But I'm not certain I understand it.**

GILES **A short definition might be useful, Mr. Williams.**

MR. WILLIAMS **Well—very over-simplified—a suspension bridge consists of a pair of cables, anchored at both ends, passing over towers at both ends: and with a series of suspenders hanging down from the cables to carry the deck.**

SUSAN **Why should they build a suspension bridge here instead of some other type? By the way, how many kinds are there?**

GILES **Check me on this, Mr. Williams. The four main classifications are the beam or girder bridge, the arch, the cantilever, and, of course, the one over there, the suspension. Right?**

MR. WILLIAMS **Exactly! And now your question, Mrs. Newton. A suspension bridge is generally used where a very long central span is required without a series of supporting piers.**

SUSAN **Over water, for example.**

MR. WILLIAMS **Yes, or, perhaps, a very wide and deep gorge, where supporting piers might have to be several hundred feet tall. They would then be unwieldy and much too expensive.**

GILES **And the central span of this bridge is one of the longest in the world, isn't it?**

MR. WILLIAMS **Well, when the bridge was completed and opened to traffic in 1967, the central span was the seventh longest, and it's likely to rank in the first ten for at least ten years.**

SUSAN **Exactly how long is it?**

MR. WILLIAMS **Three thousand two hundred and forty feet.**

SUSAN **You mean, not even a mile.**

GILES **Susan, Mr. Williams is talking about the main or central span of the bridge which is the real engineering achievement. It's measured from the centres of the towers over which the cables pass at each end, on the way down to the anchorages.**

MR. WILLIAMS **That's right. There's an additional thousand feet at each end, measured again from the centre of the towers to the cable anchorages.**

SUSAN **Cable anchorages. . . . Oh, you mean where the cables end, or start, at each end of the bridge.**

MR. WILLIAMS **Yes, each of the two cables is anchored at each end. They rise up to rest on, or bear on, specially-constructed saddles on top of each tower. And, in the space between the two towers, they form that gentle curve from which the vertical suspenders hang to take the weight of the deck or roadway.**

GILES **You follow that, Susan?**

SUSAN **Yes. I was just adding it up. One thousand, plus one thousand, plus three thousand two hundred and . . . It still doesn't add up to a mile!**

MR. WILLIAMS **No, afraid not, Mrs. Newton. The Severn Suspension Bridge—if you measure from anchorage to anchorage—is five thousand two hundred and forty feet—exactly forty feet short of a mile.**

GILES **Of course, there are also the anchorages themselves.**

MR. WILLIAMS **Oh, yes. The top of the concrete anchorage blocks in each case is part of the roadway. That's another one hundred and fifty-five feet at each end.**

SUSAN **And what about the distance from each anchorage to where the road rests on solid ground? That's also elevated.**

MR. WILLIAMS **It is. On this side the anchorage is connected to the cliff by a viaduct of something over five hundred feet long.**

SUSAN **It's a beautiful-looking bridge, but . . .**

MR. WILLIAMS **Yes?**

SUSAN **Well, from here it seems so slender and so slim.**

GILES **Isn't that what you meant when you called it 'beautiful'?**

SUSAN **I did, but—but is it safe?**

GILES **Of course it's safe!**

SUSAN **But can you test a bridge?**

GILES **They test aircraft. Why not a bridge?**

SUSAN **I know, but they start with a model in a wind tunnel before they . . . Is that what they did with the Severn Bridge?**

MR. WILLIAMS **Yes. Models of both this, and the slightly longer road bridge over the Firth of Forth in Scotland, were tested. This one, for example, can take winds up to at least one hundred miles per hour.**

SUSAN **From where we're standing, the outside edge of the deck seems very thin and it gets thicker towards the middle.**

GILES **In other words, it's streamlined. I suppose it looks the same from the opposite side?**

MR. WILLIAMS **It does. That shape was tested in the wind tunnel and found to be more stable aerodynamically. Instead of pounding against it, the wind flows over and under.**

SUSAN **I've often wondered . . . when they build a bridge like this, once the suspension cables are in place, do they start working from both ends or what? I mean, with the deck?**

MR. WILLIAMS **In this case, the first decking was hung at the centre of what is now the low point of the suspension cables.**

GILES **Didn't they prefabricate the decking at a shipyard and float it or tow it downstream?**

MR. WILLIAMS **Exactly. They quite literally made hollow steel boxes the width of the bridge and in sixty foot lengths. They were air-tight, water-tight and they floated just as a ship would.**

SUSAN **You mean, they floated or towed sixty feet of roadway down the river and then hoisted it up into place?**

MR. WILLIAMS **That's right. First the centre section, then they worked both ways from the centre towards each bank of the river. The sections, once hoisted into place, were welded together until they finally reached from anchorage to anchorage.**

GILES **Using hollow sections would make for less weight than the conventional type of bridge.**

MR. WILLIAMS **Less weight, less expensive. Easier to lift, therefore quicker to build. And, because the sections were built off the site and brought here, the bridge was safer to erect.**

SUSAN **How deep are these so-called hollow boxes?**

MR. WILLIAMS **Well, in the middle, ten feet.**

GILES **Do they remain sealed?**

MR. WILLIAMS **Oh no. Before each new section was added, two openings were made at both ends, so now there are literally two passage-ways running the length of the bridge under the top plates of the decking.**

SUSAN **But when we drive across, we don't ride on steel. It looks like any road surface.**

GILES **I suppose they must have laid a thin road surface over the top of the steel.**

MR. WILLIAMS **That's right.**

Civil Engineering

Civil engineering is claimed to be 'the art of directing the great sources of power in nature for the use and convenience of man'. The part played by civil engineers in pioneering work and in developing wide areas of the world has been and continues to be enormous.

Civil engineers must make use of many different branches of knowledge including mathematics, theory of structures, hydraulics, soil mechanics, surveying, hydrology, geology and economics.

Civil engineering was not distinguished from other branches of engineering until 200 years ago. Most early engineers were engaged in the construction of fortifications and were responsible for building the roads and bridges required for the movement of troops and supplies. The Roman armies of occupation in Europe were served by brilliant engineers but after the collapse of the Roman Empire there was little progress in communications until the beginning of the Industrial Revolution, the invention of the steam engine and the realization of the potentialities in the use of iron. Roads, canals, railways, ports, harbours and bridges were then built by engineers who adopted the prefix 'civil' to distinguish them from the military engineers and to emphasize the value of their work to the community.

Let us look briefly at some of the problems of building bridges and dams.

Building Bridges

MATERIALS USED IN BRIDGE CONSTRUCTION

Wood, brick and stone were generally used in constructing bridges until the nineteenth century. Many stone bridges in the United Kingdom are several hundred years old.

The first iron bridge was completed in 1779. Iron was commonly used for bridge construction for more than one hundred years.

Iron has been replaced by steel, which is stronger, and permits lighter members to be used.

Bridges are now made of steel or of reinforced concrete, or of steel and reinforced concrete combined, or even of aluminium alloy.

CONCRETE FOR BRIDGES

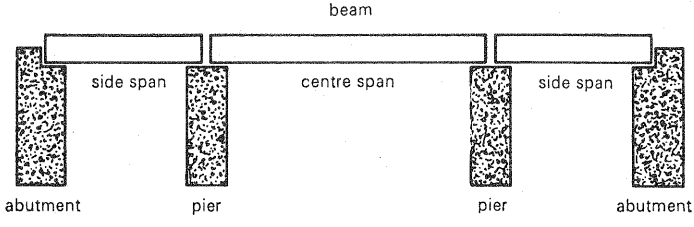


Fig. 1 — The parts of a bridge

Many modern bridges are made of concrete beams supported by concrete piers and abutments.

Concrete is strong in compression, but weak in tension. Steel, which is strong in tension, is used to counteract the tensile forces in loaded beams.

Fig. 2 — Compression and tension

REINFORCED CONCRETE

For abutments and piers and also beams, an arrangement of steel wires or rods is encased in concrete, to make reinforced concrete.

When a beam is supported at its ends, the upper part of the beam is in compression and the lower part is in tension. When the beam is subjected to a heavy load the stresses are increased. If a beam is made of concrete it is usually strengthened or reinforced by means of steel rods in the lower part of the beam where the tensile stresses are found.

PRE-STRESSED CONCRETE

The concrete can be made stronger by pre-stressing. In the simplest type of pre-stress, the reinforcement is in the form of wires which are first tensioned by stretching them. Then concrete is cast round the wires in tension. When the concrete has set, the wires are cut. The contraction of the wires is resisted because they are held by the concrete. They therefore put the concrete into compression. When the beam comes under load this compression counteracts the tensile forces.

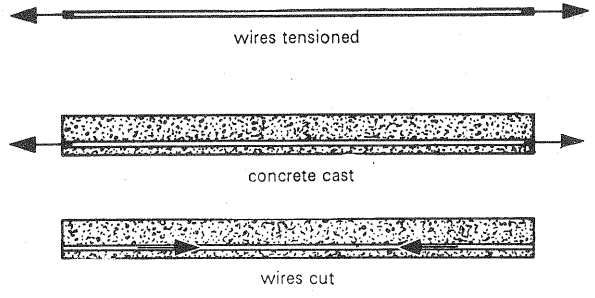


Fig. 3 — Pre-stressed concrete

Short beams, pre-stressed in this way, can be manufactured in numbers in a factory and later taken to the structure where they are needed.

SUSPENSION BRIDGES

Suspension bridges are generally used for very long spans. A pair of cables, anchored at both ends, is supported on towers. The deck is joined to the cables

by suspenders. The cables are in tension, and are usually made of many thousands of fine steel wires, which together have a greater tensile strength than ordinary steel. The deck is generally made of reinforced concrete or steel.

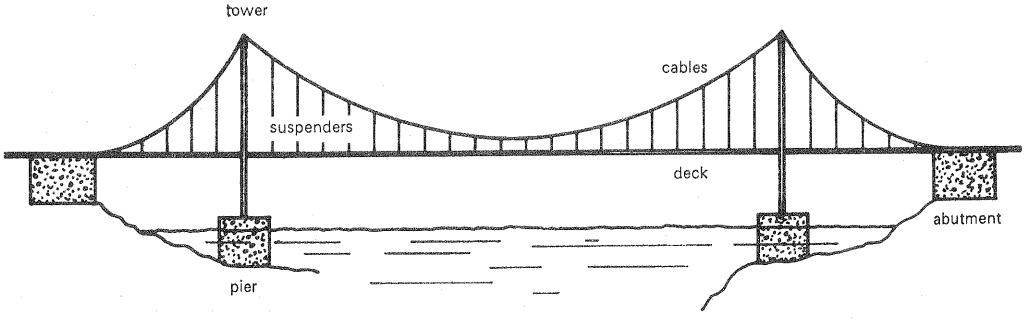


Fig. 4 — Suspension bridge

The design of suspension bridges continues to be improved. In a bridge recently built the cross-section of the deck has been streamlined to minimize the effects of cross-winds. The hollow steel boxes of which this deck is constructed require less steel than a solid deck of the same strength. The lighter deck can be supported by lighter cables, and suspenders. Thus the new design economizes on the use of steel.

Building Dams

Man, unlike the beaver, chooses materials other than trees and mud with which to impound water. The modern dam can serve one purpose, or several purposes, including storage of water for water supply, generation of hydro-electric power, irrigation of agricultural land and the regulation of rivers to prevent disastrous floods.

A dam consists basically of three parts:

1. A wall of concrete or embankment of earth or rock, which prevents the passage of water.
2. A means of releasing water stored upstream of the dam, usually by tunnel or pipeline.
3. A means of passing flood waters through or over the dam into the river channel below it—i.e. the spillway.

The type of material from which a dam is built can be simply stated as either *concrete* or *fill*, or a combination of the two.

Concrete dams are, generally speaking, feasible in steep-sided valleys or gorges where hard rock can be found on which to place the dam structure. Gravity dams in concrete are the most usual type, where water pressure on the upstream face is resisted by the mass of the dam. Such dams may be of plain construction, like a wedge in shape, the point being upwards, and in many instances are built as a number of buttresses, which can lead to economy in materials.

Where gorges exist, and where the rock is capable of sustaining heavy loading, concrete has been used in the form of arches, like those used in bridges, which are curved horizontally and in some cases vertically as well.

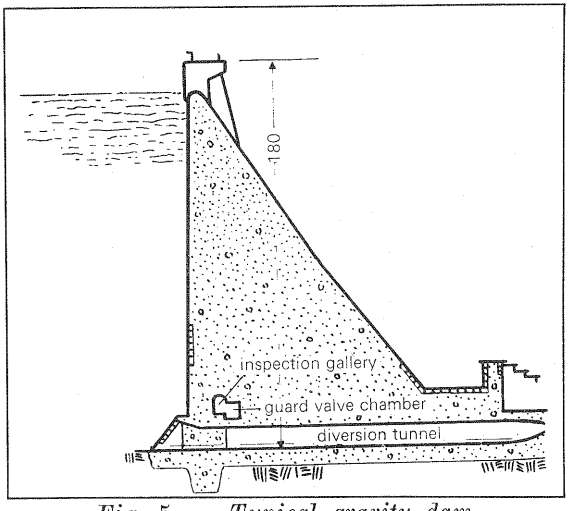


Fig. 5 — Typical gravity dam

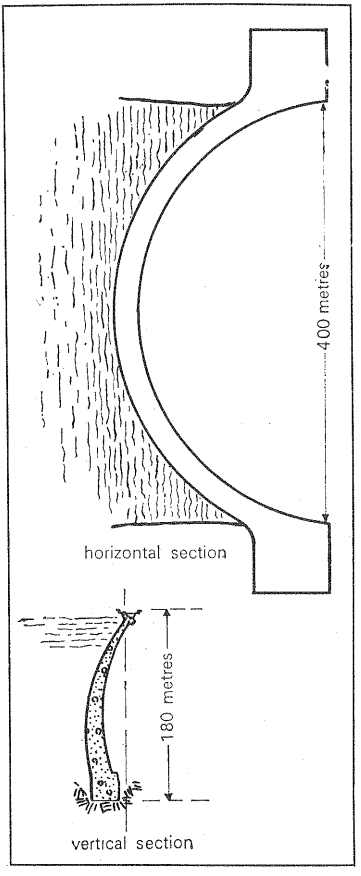


Fig. 6 — Typical arch dam

Concrete used in dams is rarely reinforced with steel, but often contains materials such as fly ash (from coal-fired power stations) which leads to economy in the use of cement.

Fill dams are usually employed in valleys which are not particularly steep-sided, and where the foundations cannot support the higher pressures arising from concrete dams. Though the volume of material used in a fill dam is considerably greater than for a concrete structure, the materials used are invariably cheaper, easy to find within a short distance of the site and can form a safe, water-tight structure.

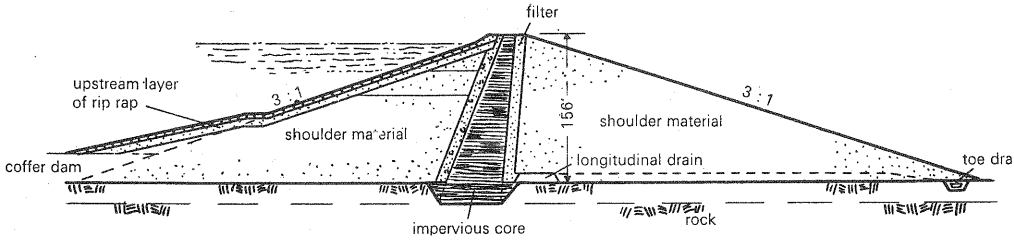


Fig. 7 — Typical fill dam

Many different materials are used in the construction of fill dams, from quarried rock to river gravel, clay and silt. Essentially, there must be a water-tight core or upstream layer, usually of clay rolled into a dense condition, which is supported by other materials which need not be water-tight. As an example, in the construction of Mangla Dam in West Pakistan, fifteen different classes of material were used, many of them having to pass through a large and complex processing plant before being placed.

All dams need sound foundations, and the nature of the bedrock under many dams entails extensive grouting of fissures and porous zones with cement or with chemicals to prevent water passing under or round the dam.

Spillways which can safely pass floodwater are of many types, and often require the boring of large tunnels. The spillway at Mangla, controlled by very large steel gates, was designed to pass a flow four times greater than that of Niagara Falls.

Tunnels are also used to supply water to power stations, and may be combined with the steel penstocks which are often the only visible evidence of hydro-electric power schemes.

It is vital to remember that a dam is designed to stop the passage of water and to store it; without means of controlling and passing both normal and flood flows

round or through the dam, the safety of the dam and of the people living in its shadow and further downstream could not be assured.

Word Study

(1) *to construct*—to put together, to build

construct
construction
constructional
constructor

It takes about two years to *construct* a large bridge.
The *construction* of a large bridge takes about two years.
The bridge would be *under construction* for two years.
Suspension bridges are usually *constructed* over water.
Brunel was a famous *constructor* of bridges and tunnels.
If a bridge collapses, it is important to find out whether the cause was a *constructional* fault (fault in construction) or an error in design.

(2) *to compress*—to press together

compress
compression
compressive
compressor

The forces in the upper part of a loaded beam are *compressive.*
The upper part of a loaded beam is in *compression.*
All permanent gases are equally *compressible.*
Solids are relatively *incompressible.*
Compressed air is supplied by a *compressor* (a mechanical pump).

(3) *to tension*—to tighten (a string, cable or tie-rod)

tension
tensile

(There are no other forms.)

In casting pre-stressed pre-tensioned concrete, it is necessary *to tension* the reinforcing wires before the concrete is cast.
The wires must be *put in tension* before the concrete has set.

The lower part of a loaded beam is *in tension.*

The forces in a cable can only be *tensile*; they cannot be compressive.

(4) *to suspend*—to hang

suspend
suspension
suspender

All the cables and suspenders being in position, the next task is *to suspend* the deck section by section.

A *suspension* bridge is used for very long spans.

(Note that *suspend* and *suspension* have other common uses in science and engineering.)

(a) *to suspend*—to stop temporarily
When ice forms on the bridge, construction work has to be *suspended.*
At what wind-speed has it been decided to suspend operations?

(b) *suspension*—a fluid mixture of liquid and solid particles
When carbon dioxide is bubbled through clear limewater, a milky white *suspension* of calcium carbonate is produced.

(5) *to maximize*—to make as large as possible
to minimize—to make as small as possible

maximum	minimum
maxima (*plural*)	minima

The streamlined cross-section *minimizes* wind effects.

What is the *maximum* height of the deck above water-level?

(6) Notice that in science words of Latin origin are preferred to words of Anglo-Saxon origin, e.g.: the scientist prefers *suspend* to *hang*, *construct* to *put together*, *compress* to *press together.*

(7) horizon
horiztonal

The distance of the *horizon* at sea is proportional to $\sqrt{h}$ where h is the height of the observer above sea-level.

To test whether a surface is *horizontal* it is necessary to apply a spirit-level in two perpendicular directions.

(8) vertex
vertical

The *vertex* of a triangle is the corner opposite the line that is selected as the base line.

To test whether a surface is *vertical* it is usual to apply a plumb-line.

(9) distinguish
distinction
distinct

How is civil engineering *distinguished from* other branches of engineering?
What is the *distinction between* civil and other branches of engineering?
The engineering profession now has many *distinct* branches.

7. Electronics

Giles Newton is writing an article on new developments in electronics. As a start for his research, he has taken Susan to a meeting with two university lecturers, Miss Baines and Dr. Abel.

GILES NEWTON **Miss Baines, my first impulse is to ask: 'What's new in electronics?' I suppose that would be silly?**

MISS BAINES **No, the question's all right, Mr. Newton, but I'm afraid a comprehensive answer would take days—weeks. Dr. Abel is what we call our 'walking encyclopaedia'. He likes to keep track, in a general sort of way, of all new developments.**

SUSAN NEWTON **Well, Dr. Abel? Miss Baines has left it to you.**

DR. ABEL **And she's done me no favour, Mrs. Newton. There's something new in electronics almost every day. Where do I start?**

GILES **What about the new 'black box' for lorries?**

SUSAN **Black box? But isn't that the flight recorder in an aircraft?**

DR. ABEL **Yes, it is, but the term is now often used for any enclosed electronic device capable of performing many functions. The 'black box' for lorries is an electronic warning and indication system to keep check on fifteen possible danger points in a motor vehicle.**

MISS BAINES **Yes, it was first tried out with tankers.**

GILES **What are some of these fifteen points?**

MISS BAINES **There's an indicator for low engine oil pressure. And it shows high water temperature in the radiator as well as low water level.**

DR. ABEL **Don't forget the instruments that show low air pressure, both in the braking system and in the tyres.**

SUSAN **But the modern motor vehicle already has some of those things, hasn't it?**

DR. ABEL **Yes, but this electronic system gives instantaneous warning, both visually and audibly. The driver would have to be deaf and blind to miss any of it. And the warning indicators remain in operation until the faults have been rectified.**

MISS BAINES **Then there's the micro-electronic instrument that enables the blind to read conventionally printed magazines and newspapers.**

DR. ABEL **Yes, that means they won't have to rely only on Braille, talking-books and so on.**

GILES **Miss Baines used the term 'micro-electronic'. Does that mean miniaturization?**

DR. ABEL **No, it's a step further, into the sphere of micro-miniaturization. And you wouldn't be wrong to call it 'miniaturized-miniaturization', which makes it very small.**

MISS BAINES **To my mind that's the most exciting field, particularly the mini-computer.**

SUSAN **Just how 'mini' can it be?**

MISS BAINES **Small enough to fit into the pocket of an ordinary jacket.**

DR. ABEL **Let me put it this way: it's already possible to have one hundred and forty distinct circuits on a one-inch disc of silicon.**

GILES **But all this has to be more than just an engineering game. I mean, micro-miniaturization must serve some useful purpose. I'd like to know what it is.**

SUSAN **Doesn't it mean you can put more equipment into spacecraft?**

DR. ABEL **Yes, Mrs. Newton. But come down closer to the ground, and consider modern aircraft. They carry a big load of electronic equipment.**

GILES **I see. The point is, if you make this apparatus smaller, it'll be lighter and the aircraft can carry a bigger pay-load.**

DR. ABEL **Yes, but weight isn't the only factor.**

MISS BAINES **Once again, the computer is the perfect example. Roughly speaking, if you scale down all linear dimensions in the ratio of one to ten, the speed of operation is scaled up ten times.**

DR. ABEL **And, at the same time, you can also decrease the cost of production and running.**

SUSAN **When you consider how quickly computers operate already, what's the advantage of a further increase in speed?**

DR. ABEL **It's very simple, Mrs. Newton. Imagine yourself in a fast aircraft coming in for a landing in dense fog and guided by computers. Wouldn't you want the speed then?**

SUSAN **Point taken, Dr. Abel!**

GILES **This micro-miniaturization can lend itself to greater safety in another way, can't it?**

DR. ABEL **In several ways. What did you have in mind?**

GILES **Duplicate systems. If one electronic device fails, for example, a relay would automatically switch on a duplicate.**

DR. ABEL **True, but the possibility of a failure is also decreased.**

SUSAN **How?**

DR. ABEL **These micro-miniaturized devices have no bits of wire soldered here and there. The result is no danger of broken joints.**

SUSAN **But suppose a fault does occur? How do you repair it?**

MISS BAINES **Using test equipment, you locate the faulty circuit, then simply withdraw it, throw it away and plug in a new one.**

SUSAN **Just imagine that in the home—a complete set of spare circuits for every electrical gadget.**

DR. ABEL **It'll happen one day!**

GILES **Then, Susan, you could do your own electrical repairs!**

The Growth of Electronics

The first phenomena that we now recognize to be caused by electrons were noticed during the nineteenth century when inventors like Edison were studying electrical effects in evacuated glass bulbs and tubes. Sometimes certain areas of the almost completely evacuated vessel would become luminous and glow with blue, green or red light. Though these effects were exploited to produce colourful discharges—now well known as the fluorescent neon-tubes used in advertising—the cause of these phenomena was then unknown.

Then, in 1899, J. J. Thomson discovered the first of the fundamental physical particles—the electron. This particle has a very small mass but carries a negative electric charge. The electron is therefore very responsive indeed to electric and magnetic fields. Soon after it had been discovered, scientists and inventors began to put it to work.

The next invention established the new applied science of electronics. In 1904 J. A. Fleming invented the diode valve which, with later elaborations, became the device which made radio possible. Marconi's experiments in 1901, in which he successfully transmitted the first messages by radio across the Atlantic, had

demonstrated that radio waves could be used for telecommunications but it took some time to develop the first working radio systems. The first radio broadcasts were made in Britain in 1927 on short wave.

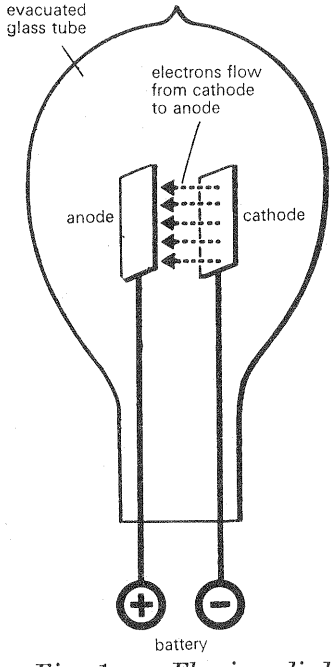


Fig. 1 — Fleming diode

So electronics is the basis of all telecommunications systems. The radio valves which contained a gas at very low pressure are now being replaced by solid-state semiconductor devices called transistors which are much smaller and have a longer life than gas valves. Since the last war a whole new industry concerned with the manufacture and exploitation of solid-state electronics has been established. One new branch of this field has led to the development of computers which contain enormous numbers of transistors, minute magnetic cores and other new electronic solid-state devices.

The electronics industry now embraces radio, television, computers, automatic control and many other areas. Electronics is a field in which scientific research and technical development is still intensive, and so many more manifestations of the versatility of the electron can be expected.

Cathode Ray Tube

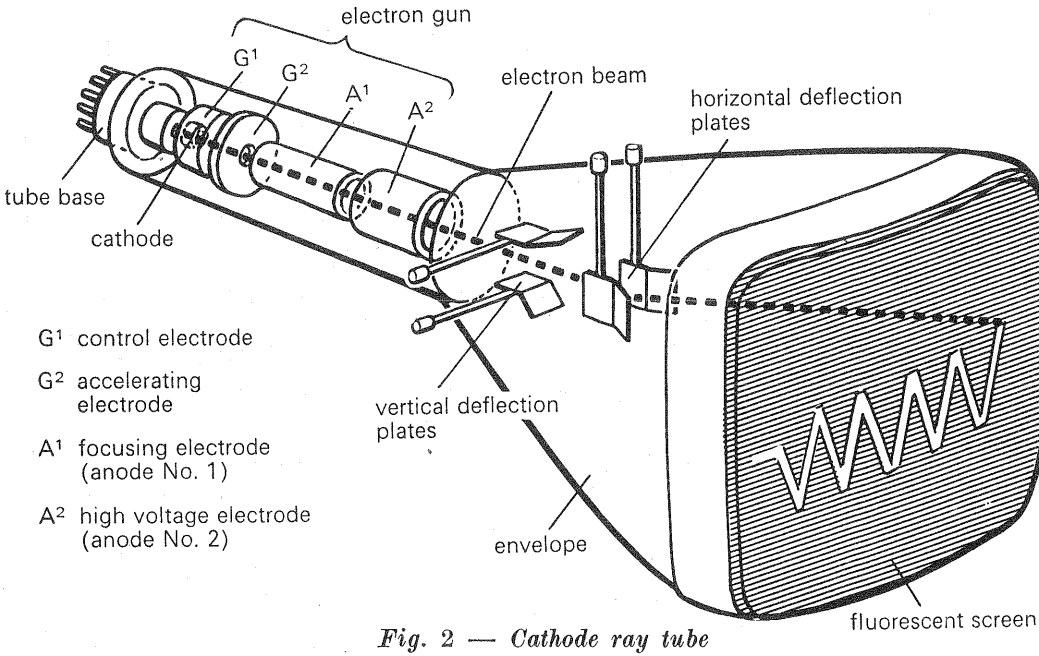


Fig. 2 — Cathode ray tube

The cathode ray tube (C.R.T.) is one of the most important of the electronic devices because it made television possible. In the C.R.T. a thin beam of electrons moving in an evacuated glass vessel is made to respond to changes in the electrical and magnetic fields imposed on it. The response of the electronic beam is instantaneous because its inertia is negligible. It is therefore very sensitive to any forces which act on it. When the beam of electrons strikes the front of the cathode ray tube it activates a phosphor—a material which converts electronic energy into the light which shows through the glass.

Miniaturization

There are several advantages in making computers as small as one can. Sometimes weight is particularly important. A modern aircraft, for example, carries quite a load of electronic apparatus. If it is possible to make any of these smaller, and therefore lighter, the aircraft can carry a bigger pay-load. This kind of

consideration applies to space satellites and to all kinds of computers that have to be carried about.

But weight is not the only factor. The smaller the computer the faster it can work. The signals go to and fro at a very high but almost constant speed. So if one can scale down all dimensions to, let us say, one tenth, the average lengths of the current-paths will be reduced to one tenth. So, very roughly speaking, scaling down of all linear dimensions in the ratio of one to ten also gives a valuable bonus: the speed of operation is scaled up 10 times. Other techniques allow even further speed increases.

This increase of operation is a real advantage. There are some applications in which computers could be used which require very fast response times. Many of these are military, of course; but most military applications also have applications in engineering sooner or later. For example, automatic blind landing of aircraft requires continuous computer calculations which result in control of the aircraft flight. The more immediate the responses are, the more stable that control can be.

Another advantage is that less power is required to run the computer. In space vehicles and satellites this is an important matter; but even in a trial application we need not waste power. Sometimes a computer takes so much power that cooling systems which require still more power have to be installed to keep the computer from getting too hot, which would increase the risk of faults developing. So a computer which does not need to be cooled saves power on two counts.

Another advantage is reliability. Mini-computers have been made possible by the development of integrated circuits. Instead of soldering bits of wire to join separate components such as resistors and capacitors sometimes in the most intricate networks, designers can now produce many connected circuits in one unit which involves no soldering and therefore no risk of broken joints at all. And now that transistors and other solid-state devices are used instead of valves, printed circuits with their solid-state components (protected by packing in insulating resins) have a very long life indeed. A computer can be built up of large numbers of similar units of this kind.

Repairs of the old kind (with soldering iron and so on) are no longer needed. If one of the component circuits develops a fault, all that is needed is to locate the faulty unit, throw it away and plug in a new one.

All these devices, small as they may be to the eye when hundreds of circuits can be packed on to one square inch, are still much larger than they need be to do the jobs they have to do. So the problem is one of finding ways of making these complicated patterns automatically very precisely, and yet smaller and smaller. The limit is a long way off yet. Human brains have more than 100 million cells per cubic centimetre but there is no reason to think that we cannot pack solid-state devices more densely than this.

Computers could then easily be built up from these micro-miniaturized components to have data stores or memories as large as are needed for any job one could imagine. The main problem of very large stores is finding one's way about them, but if they are large in information capacity, but small in physical dimensions, with present day techniques much time and cost can be saved.

Word Study

(1) USEFUL WORDS

reduce
reduction

(*See also Aircraft*)

The average lengths of the current-paths will be *reduced* to one tenth.

The main effect of the atmosphere is the *reduction* of the violent changes of temperature.

develop
development

Sometimes a computer takes so much power that cooling systems which require still more power have to be installed to keep it from getting too hot, which would increase the risk of faults *developing*.

The *development* of miniaturized computers has been important in the aircraft industry.

electron
electronic
electronics
electric
electricity
electrical

The *electron* is a sub-atomic particle with a negative charge.

At this university it is possible to study *electrical* engineering and *electronics*.

The television receiver is an *electronic* device.

He is an *electrical* engineer who has specialized in electric traction.

(2) OTHER USEFUL WORDS

versatile	versatility
ductile	ductility
reliable	reliability

8. Shipbuilding

Giles and Susan Newton are talking to the technical director and the production manager of a shipbuilding company.

GILES NEWTON **Sir Henry, isn't the trend towards bigger and bigger ships all the time?**

SIR HENRY **That's partly true. British shipyards, for example, have orders for several tankers all in excess of a quarter of a million tons deadweight. That's so, Mills, isn't it?**

MR. MILLS **Yes, that's right. And it's a safe bet there'll be half-million-ton tankers on the high seas well before 1980. In Northern Ireland a new building dock is under construction in which it'll be possible to build million-tonners.**

SUSAN NEWTON **Didn't somebody say that ships don't necessarily have to be ship-shaped? . . . I mean, not shaped like ships . . . Oh! I'm getting all mixed up!**

GILES **My wife is thinking of the tendency to move away from the traditional shape of a hull.**

SIR HENRY **Well, Mr. Newton, I heard a lecture a little while ago by the chairman of a shipbuilding company about a type of hybrid vessel embodying hovercraft principles. The lecturer visualized it as a huge tea-tray, supported partly on an air cushion and partly on hydrofoils running just below. He suggested that such craft could be used on the North Atlantic.**

MR. MILLS **Didn't he mention large ocean-going catamaran ships?**

SIR HENRY **He did, and we know it's possible, with some of these new ideas, to build large ships to travel as fast as one hundred knots.**

SUSAN **It almost sounds like science fiction.**

SIR HENRY **Science, Mrs. Newton, but not fiction. Each launching of a vessel of the newer and unconventional variety is usually an improvement on, or an enlargement of, those previously built.**

MR. MILLS **Also, there are new methods of ship-handling, both at sea and in dock.**

GILES **Does that mean automation?**

MR. MILLS **Yes. In 1960 a tanker with a deadweight of seventy-five thousand tons would have required a crew of approximately sixty. Today one of the mammoth tankers nearly four times that tonnage will operate with personnel numbering no more than twenty-five.**

SIR HENRY **You see, increasingly complex electronic equipment is being used on board ship to assist in the navigation, control of engine room and control of cargo.**

MR. MILLS **We're very close to the time when a complete computer system can be installed to assist in every phase of ship-handling. For example, there are ships at sea today with automatic helmsmen. The gyro-compass automatically keeps the ship on a predetermined course. At the same time, there is sufficient leeway for weather routing. This would mean a shore-based computer feeding weather information into the shipboard computer which would automatically alter course to find the optimum weather conditions.**

SIR HENRY **Meanwhile, shipboard radar would supply this automated helmsman with the locations of other ships so that, if necessary, it could take what airmen like to call evasive action. Even the engines can be operated from the bridge.**

GILES **How would the system work?**

MR. MILLS **Well, real automation at sea requires controls that operate complex interacting systems so that they give their highest overall efficiency. On a large and complicated ship that would involve almost continuous measurement of a large number of engine-room pressures, temperatures, fuel rates, power output and propeller characteristics. These factors must be adjusted rapidly to ensure maximum propulsive efficiency and minimum fuel cost.**

SUSAN **Which brings us back to the old story that a computer can make the necessary adjustments more quickly and more accurately than a man.**

GILES **Can computers also be used to automate the loading and unloading of liquid cargo?**

SIR HENRY **For tankers, yes, also for bulk cargo, or the new cargo-containers for ships other than tankers.**

SUSAN **Next they'll be automating shipbuilding as well!**

MR. MILLS **But, Mrs. Newton, that's already been done in many ways. Not so long ago all steel plates to be cut for building a ship were marked out by hand. This method was replaced by optical following, a system whereby steel plates are cut automatically by gas burners directly guided from scale drawings. Nowadays, the movement of the cutting machines is often controlled by information stored on computer tape. This is called numerical control.**

SIR HENRY **There's also welding. Nearly all of it required in shipbuilding can be automated in a variety of ways. And I wager I can guess what's in Mrs. Newton's mind.**

SUSAN **And I'll bet you're right. I still think it sounds like science fiction!**

Ship Design

Scale models are used by naval architects to assist in designing the form of the hull. To ascertain the power required to drive the ship the model can be fitted with propellers, and then propulsion experiments can be carried out in a large testing tank. The dimensions of the ship will depend on a number of factors, and the designer must make sure that the required displacement up to the designed draught is provided in relation to the specified deadweight carrying capacity. He will also take into consideration the shape or form of the ship that is needed to meet the required service speed and the stability characteristics.

When all model tests have been completed the naval architect is able to estimate the horse-power needed to propel the ship at the design speed. In consultation with a marine engineer, he then makes a critical examination of the calculations.

Three wave systems are generated by the passage of a ship through the water: the bow system, the stern system and the transverse system. Wave-making resistance follows Froude's Law of Comparison, the law of dynamic similarity,

which states that the resistance of geometrically similar ships will vary as the cube of their linear dimensions if the speeds are in the ratio of the square root of the linear dimensions.

$$\frac{R_r}{r_r} = \frac{L^3}{l^3}, \text{ provided } \frac{V}{v} = \sqrt{\frac{L}{l}}$$

There are a number of alternatives available for the ship's main propulsion machinery: the slow-speed diesel engine; the medium-speed diesel engine (which may be direct-drive in small ships or, for larger ships, where more than one engine is required to meet powering needs, coupled through gearing to a single shaft); the steam turbine with oil-fired boilers; the gas turbine; diesel or turbo-electric propulsion and the steam turbine in conjunction with steam produced by nuclear energy. Over a wide power range the diesel has the great advantage of operating at a low fuel cost, although at higher powers maintenance costs can considerably reduce the advantage of low fuel consumption. Steam turbines are often used for higher powers but diesel engines of very high power (up to about 60,000 horse-power) are available and being increasingly used. Gas turbines have certain disadvantages because of the very high temperatures at which they operate and the heavier and cheaper fuel oil used, which causes corrosion of the turbine blades.

An electronic computer can be used to perform speedily various calculations for the ship, including those for hydrostatics, stability, subdivision, capacity, vibration, resistance, strength and motion in a seaway. Shipbuilders are required by law to supply new ships, after completion, with a booklet giving the vessel's trim and stability characteristics for certain loading conditions. The designer has to observe the requirements of a Classification Society like Lloyd's Register of Shipping, and government regulations which concern shipping such as those of the Board of Trade in the United Kingdom.

Shipbuilding Production

The basic design having been agreed with the shipowner, working drawings are prepared. Schedules are drawn up for materials and production. Shipbuilding managements nowadays often use a system of network analysis, for example P.E.R.T. (Programme Evaluation and Review Technique) which employs the electronic computer.

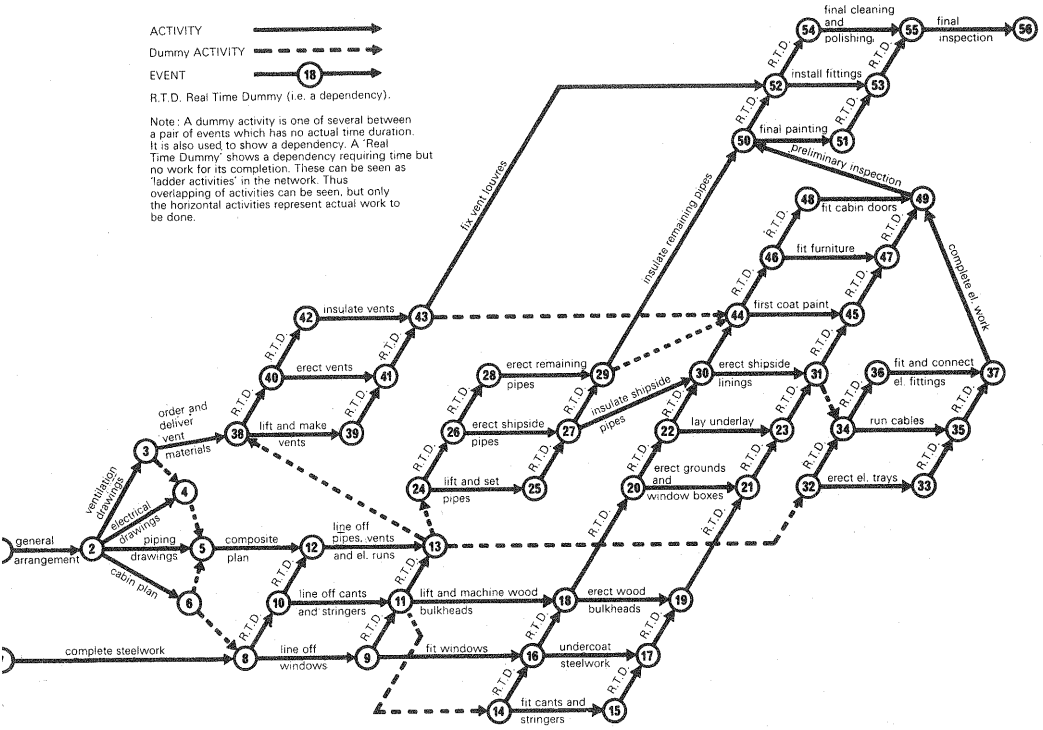

ACTIVITY
Dummy ACTIVITY
EVENT
18
R.T.D. Real Time Dummy (i.e. a dependency).
Note: A dummy activity is one of several between a pair of events which has no actual time duration. It is also used to show a dependency. A 'Real Time Dummy' shows a dependency requiring time but no work for its completion. These can be seen as 'ladder activities' in the network. Thus overlapping of activities can be seen, but only the horizontal activities represent actual work to be done.
general arrangement
ventilation drawings
electrical drawings
piping drawings
cabin plan
order and deliver vent materials
lift and make vents
composite plan
line off pipes, vents and el. runs
complete steelwork
line off cants and stringers
line off windows
lift and machine wood bulkheads
fit windows
fit cants and stringers
erect wood bulkheads
undercoat steelwork
erect grounds and window boxes
lay underlay
erect shipside linings
erect el. trays
run cables
fit and connect el. fittings
complete el. work
fit cabin doors
fit furniture
first coat paint
preliminary inspection
final painting
install fittings
final cleaning and polishing
final inspection
fix vent louvres
insulate vents
erect vents
erect remaining pipes
erect shipside pipes
insulate shipside pipes
insulate remaining pipes
lift and set pipes
R.T.D.

Fig. 1 — Part of a PERT analysis network

This shows diagrammatically as a network the series of *events* (e.g. decisions of management) and *activities* (operations requiring time or resources). The diagram allows the processes to be studied and the relationship between the various parts of it to be analysed.

Hull Construction

Before ordering from the mills, the design and drawing offices carefully calculate the *scantlings** of the steel material from the rules of the Classification Society under whose survey the ship is to be built. When the steel is delivered to the shipyard, it passes through the levelling rolls, and then the shot-blasting machine, where mill-scale and any surface corrosion are removed. After this the

* *scantlings:* measurements of the thickness of steel material used in shipbuilding.

surfaces of the material are sprayed with a special shot-blast priming paint. The thickness of this priming coat is carefully controlled to avoid difficulties with other processes (such as welding) which will follow as the material is worked and prepared for assembly into the ship structure. Some shipyards prefer to level plates after shot-blasting.

The steel plates are then passed to the plate-preparation shops where they will be channelled to various machines according to their ultimate function in the structure. Large, flat plates for the shell, decks or bulkheads will be processed on edge preparation machines which may have triple-headed burners to prepare the plate-edge for the welding process. Plates which have to be shaped, for example, the shell plates at the bilge of the ship, will then pass to the plate rolls. Other plates, forming part of the internal structure (such as transverse floors, webs, etc.) will be processed on profile-burning machines, with the movement of the cutting head controlled either numerically by computer-tape, or optically when the control head follows a specially prepared scale drawing of the part to be cut.

The various prepared parts are now formed into minor assemblies in the sub-assembly shop, and are then built into much larger units in the prefabrication shop. Here the seams and butts of the basic plating are welded, and the stiffeners, webs, etc., added. The size of the unit depends on the crane capacity available in the shop and at the building berth where the prefabricated units are erected, *faired** into the structure and welded to form the ship.

Before erection, the building berth is prepared and the blocks, shores and ribbands which will support the structure are carefully laid out to a predetermined pattern, and at the declivity necessary for the launching of the ship. Shipbuilders no longer 'lay a keel', but 'place the first prefabricated unit on berth'. In shipyards where suitable heavy lift capacity exists, whole deckhouse superstructures, including a proportion of the internal fitting, may be lifted on to the ship in one piece. Complete bow or stern assemblies (the latter including stern frame and shaft bossings, if fitted) will be erected as a unit.

Electronic Equipment

Complex electronic equipment is being increasingly utilized for navigational purposes and the control of the engine room and, in the case of tankers, the handling of liquid cargo. The time is not far off when it will be economically feasible to install a complete computer system to assist in the running of the ship.

* *faired* (in shipbuilding): brought together so that the parts fall into place.

The automatic helmsman makes it possible for the ship's gyro-compass to keep the ship on a predetermined course. This could save £50,000 over fifteen years if fitted to a 50,000 ton bulk carrier.

The data logger device has been fitted to ships' engine rooms. This device continuously monitors a number of operations in the engine room. It records information from electronic detecting devices installed throughout the ship. Temperatures at different points in the engine are measured by means of thermo-couples and resistance thermometers. Pressures are obtained from strain gauges and bellows; speeds of rotation of different shafts, including the propeller shaft, are measured by other devices. Electrical loads, in the case of electrically-powered ships, are measured by watt-meter circuits. Various other transducers measure such things as torque, viscosity, tank contents, salinity and flow rate.

This information, fed into electronic circuits, produces a log automatically, showing how the conditions vary from minute to minute. Other electronic circuits compute peak fuel injection pressures, shaft horse-power, average ship's speed, and average revolutions of engine. This automatic method has been found to be more satisfactory than manual logging, and much less wasteful of time. The information so logged can be produced in the form of punched tape which can be transmitted by radio to the company's shore-based computer, where the information is processed and ultimately results in the saving of operating costs.

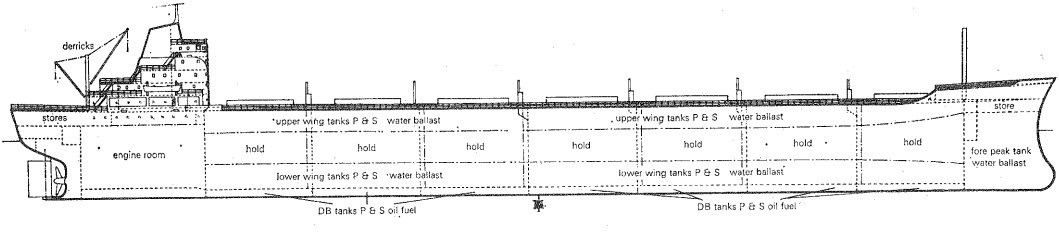


Fig. 2 — Medium sized bulk carrier

Word Study

(1) automate
automatic
automated
automation

Welding can be *automated* in a variety of ways.

There are ships at sea with *automatic* helmsmen.

The gyro compass *automatically* keeps the ship on a predetermined course.

Automation at sea requires controls that operate complex interacting systems.

The shipboard computer would *automatically* alter course.

(2) propel
propeller
propulsion
propulsive

Speeds of rotation of different shafts, including the *propeller* shaft, are measured.

These factors must be adjusted rapidly to ensure maximum *propulsive* efficiency.

There are various possible alternatives for ship *propulsion* machinery.

The horse-power needed to *propel* the ship must be calculated.

(3) power (*noun*)
power (*verb*)

The *power* needs of the ship must be ascertained.

In the *power* range 3,000 to 10,000 *horse-power* diesel has advantages.

The ship can be *powered* by any well-tried engine.

The ship will be *powered* by steam turbines.

(4) control (*noun*)
control (*verb*)

Real automation at sea requires *controls* that operate complex interacting systems.

The movement of the cutting head is *controlled* either numerically by computer-tape or optically.

The *control* head follows a specially-prepared scale drawing.

(5) stable
stability
stabilize

The decision in regard to dimensions will depend on the *stability* of the hull.

The ship's *stabilizers* are driven by electric motors.

(6) *Notice these prefixes:*

super-	structure
	superstructure
pre-	fabric
	prefabricate
	prefabrication
	determine(d)
	predetermine(d)

9. Computers

Giles Newton and his wife, Susan, are visiting a large computer installation in the head office of a group of warehouses dealing with engineering tools. They are talking to Henry Mitchell, an expert on computers.

MR. MITCHELL **I'm afraid, Mrs. Newton, you're not *quite* accurate when you call a computer an 'electronic brain'.**

SUSAN NEWTON **Oh? But most people do.**

MR. MITCHELL **Yes, it was given that title by some misguided journalist not long after the first modern electronic computer was built in 1946.**

GILES NEWTON **It *is* electronic, Mr. Mitchell, so therefore you must be objecting to the word brain.**

MR. MITCHELL **Exactly, Mr. Newton. There are similarities with the human brain, but there is one very important difference.**

SUSAN **The computer is better?**

MR. MITCHELL **In some ways, yes; but not in something which is quite fundamental.**

GILES **Mr. Mitchell, do you mean the fact that the machine is controlled by man?**

MR. MITCHELL **I do. You see, despite all its accomplishments, the so-called electronic brain must be programmed by a human brain.**

SUSAN **Programmed?**

GILES **Yes, Susan, a program is a sequence of instructions prepared for the computer for a specific calculation, or series of calculations, enabling the computer to solve a given program.**

MR. MITCHELL **The point is, that a human tells the machine what to do, when to do it and how it is done.**

SUSAN **I see! Do you also program information for the computer's memory?**

MR. MITCHELL **Correct, except the word memory has rather gone out of fashion. The computer doesn't really remember. Information is stored in it. We refer to core storage, or the store of data.**
(*The door opens.*)

MR. BRINTON **Mr. Mitchell, the machine's free now for a real time demonstration.**

MR. MITCHELL **Thank you, Jack. If you'd like to follow me. . . . These are called interrogating typewriters.**

GILES **And that's the input–output system?**

MR. BRINTON **That's right. It's the method best suited to the particular needs of this organization.**

MR. MITCHELL **The operator—this young lady—types the information or questions, or both.**

OPERATOR **Yes. This produces two very different copies.**

GILES **One's an ordinary typewritten copy.**

MR. MITCHELL **That's right. Then her typing also sends pulses down a line, an ordinary telephone line. And this simultaneously cuts the information or question on to a paper tape which is fed into the computer. I think Jack Brinton here can tell you the rest.**

MR. BRINTON **Well, this is head office. We also have eight large warehouses scattered throughout the British Isles, each with a duplicate of what you see here.**

SUSAN **Each with a computer?**

MR. BRINTON **Oh, no, just one computer, and it's in this building.**

SUSAN **And the eight warehouses are all connected to the same computer?**

MR. BRINTON **Yes. Whenever any stock is received by or despatched from one of those warehouses, an operator sends the information on-line to the central processor. That gives us a complete running inventory. By the way, we supply all types of tools to the retail trade.**

MR. MITCHELL **Mr. Newton, I thought it would make a good demonstration if you were to put any sort of question you like about the inventory to the computer. Here it is.**

GILES **Oh, well . . . How many six-inch screwdrivers are there in stock? Just the total for the eight warehouses.**

MR. BRINTON **All right. Will you process that, please, Margaret?**

OPERATOR **Yes, Mr. Brinton.**

(The operator types the question, and the reply is received immediately from the computer.)

SUSAN **How soon will we get the answer?**

MR. MITCHELL **It's there already, on the other machine.**

SUSAN **It couldn't. . . . It is! It says: '6″ screwdrivers 14 gross.'**

MR. MITCHELL That's known as real time processing.

GILES So real time is a method of processing data so fast there's virtually no time-lag between enquiry and result.

MR. MITCHELL Correct. For example, in the case of a man driving a car at, say, thirty miles per hour he can normally solve all his driving problems in real time; whereas at a hundred miles per hour he may not be able to.

SUSAN I suppose, Mr. Mitchell, there must be many scientific uses for computers?

GILES Weather forecasting, for example?

MR. MITCHELL About a hundred years ago somebody had a theory for forecasting weather based on reports from all over the world. Unfortunately, it would have required sixty-four thousand skilled clerks working full-time.

GILES I know about that. They use a similar system today, and one relatively small computer does the same work in only half-an-hour.

SUSAN Is speed the only advantage?

MR. MITCHELL It's one of them. Accuracy is another—provided the computer is given accurate information to start with.

SUSAN Can you give us another example?

MR. MITCHELL Well, in medicine computers help researchers to test drugs by projecting information gained in limited trials. As a result, large-scale tests are not only becoming safer but also yielding far more useful information.

GILES Computers can also make mistakes, of course.

MR. MITCHELL Provided there is no hardware fault, the computer does not make a mistake. But its results are only as good as the information with which it is programmed.

Let's go back to the office and we can talk about other scientific uses of computers.

Come this way.

Computers

We might list the essential constituent parts of a digital general purpose computer as follows. First, core store (sometimes called memory) for holding numbers, both those forming the data of the problem and those generated in the course of the calculation. It is also used for storing program instructions. Second, an arithmetic unit, a device for performing calculations on those numbers. Third, a control unit, a device for causing the machine to perform the desired operations in the correct sequence. Fourth, input devices whereby numbers and operating instructions can be supplied to the machine, and fifth, output devices for displaying the results of a calculation. The input and output devices are called peripherals.

The usual method for inputting data for processing into a computer is via an input peripheral such as a punched card reader or punched paper tape reader or from magnetic tape. The computer is programmed to accept data in any or all of these media. The computer operator, in order to start the input process, will type a 'go' message on the console typewriter. For real time processing the operator will use an interrogating typewriter. This asks a question of the computer about the state of specific files of data already on line to the computer. The data may be stored, or it may be sorted according to a plan desired by the programmer. It may be merged with existing information already in the store. Of, if we want immediate 'answers' or output it could be by printer, that is an output device for spelling out computer results as numbers, symbols or words. These vary from high-speed printers to electric typewriters.

A sequential digital computer works as follows. The core store is simple. A magnetic core is a tiny ring of ferromagnetic material, a few hundredths of an inch in diameter. Each core is pressed from a mixture of ferric oxide powder and other materials, and then baked in an oven. Apart from its compact size, which is a decided advantage in computer design, the important characteristic of the core is that it can be easily magnetized in a few millionths of a second. And, unless deliberately changed, it retains its magnetism indefinitely.

Cores are placed on a wire like beads on a string, and if a strong enough electrical current is sent through the wire, the cores become magnetized. The direction of the current determines the polarity or magnetic state of the core. If the direction of current is reversed, the magnetic state is changed. Consequently, the two states can be used to represent 0 or 1, plus or minus, yes or no, or on or off conditions.

More than one million cores are used in some large core stores. Because any specified location of storage must be instantly accessible, the cores are arranged

so that any combination of ones or zeros representing a character can be written magnetically or read back when needed. To accomplish selection, two wires run through each core at right angles to each other.

If half the current needed to magnetize a core is sent through each wire, only the core at the intersection of the wires is magnetized. No other core in the string is affected.

Using this principle, a large number of cores can be strung on a screen of wires; yet, any single core in the screen can be selected for storage or reading without affecting the others.

Really powerful computers continue to be bulky and to require special provision for their housing. This is largely because the electronic components do not make up the major part of the bulk of the machine. Much more space is taken up by the input devices, high-speed printers, magnetic tape units and other peripheral equipment, to say nothing of the operating staff needed to run a powerful installation. The power consumption of these machines is also not very much less than that of the comparable (although less powerful) vacuum tube machines that they displace.

The future will bring great development in the mechanical devices associated with computer systems. For a long time these have been the weak link from the point of view of both efficiency and of reliability.

Magnetic tape is now widely used in the larger digital computer systems, and provides a functionally convenient means of storing information in bulk. From the mechanical and economic points of view, however, high-speed magnetic tape units are complicated, noisy and need a good deal of maintenance. High-speed storage of information has always been a limiting factor in computer development. Scientists have recently been looking for some substitute for the ferrite core which would enable higher speeds of storage to be achieved. Much work has been done with thin films of magnetic material deposited by evaporation in a vacuum. The films are about 0·3 microns thick, and are deposited in blobs a few millimetres in diameter.

Computers in Business

Communication with the machine is the programmer's responsibility. Computer programming consists of producing detailed logical step-by-step instructions which are ultimately obeyed by the computer—'software' for the 'hardware'. Initially the programmer checks the detailed specifications supplied to him by

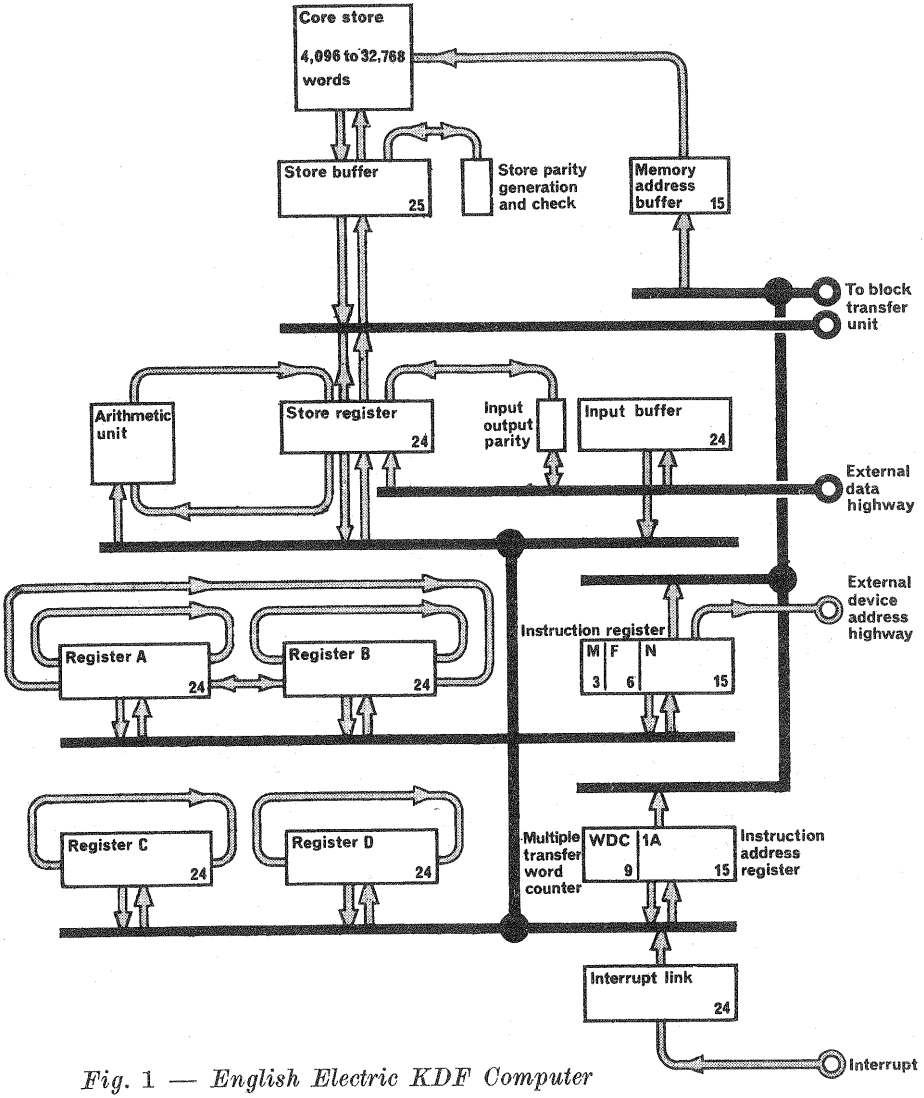


Fig. 1 — English Electric KDF Computer

the systems analyst and then produces an overall flow-chart for the run involved. It is advisable for him to check this and subsequent detailed flow-charts with the systems analysis to ensure that the required processing will be performed. After this the actual coding is undertaken. The programming language used will depend on the computer type and size, the frequency with which the job is likely to be run, its size, and the duration of each run. A language may range from the detailed 'lower level' very close to that immediately understood by the particular computer, to the high level (such as COBOL* or FORTRAN †) which can be rendered automatically acceptable to a wide range of computers.

Program tests of increasing stringency follow and when finally proved the run can be incorporated in the library of operational programs.

The first applications implemented are often clerical routines which involve a high volume of paperwork and little element of decision making. This is often a sound approach as it enables many levels of staff to become familiar with some features of computer usage. However, the major economic returns are usually in the second wave of applications which use the data then available in the computer-held files created and used by the initial applications. Computers can provide analyses of every operation in business and these analyses can reveal vital trends in every field from buying to marketing.

Word Study

(1) to implement
implementation

We cannot *implement* our computer program until the tests on the computer peripherals have been completed.

Now that the plans for installing the computer have been approved, we start at once on their *implementation.*

(2) to compute
to computerize

Here is a program for *computing* the value of π to as many decimal places as you need.

* COBOL: COmmon Business Orientated Language.
† FORTRAN: FORmula TRANslator.

We are planning to *computerize* all the clerical pay-roll routines.

(3) to automate
automatic
automation

(*See also Shipbuilding*)

We propose to install one of our own computers to *automate* all the mechanical processes involved in manufacturing our computers.

The *automation* of this process will require heavy capital expenditure and careful planning.

(4) to affect
to effect
effect
effective

The *effect* of the modification was negligible.

The modification has not *affected* the result.

Though the modification has been *effected* it has been *ineffective*.

10. Lasers

Susan Newton turns off the television set.

GILES NEWTON **Susan, I was enjoying that programme!**

SUSAN NEWTON **I want to know something, Giles, about laser beams. You've read the subject up, but I know nothing about it.**

GILES **But we're going to see a demonstration tomorrow.**

SUSAN **Yes, I know, but if I'm going along as your wife or your secretary—or both—I'll be more of a credit to you if I know a little bit about it in advance.**

GILES **Okay! What do you want to know?**

SUSAN **Well, what is it? What does the word 'laser' mean?**

GILES **Light Amplification by Stimulated Emission of Radiation.**

SUSAN **Oh yes, I see. L.A.S.E.R. laser. Quite simple, really!**

GILES **Once it's been explained to you, of course. Do you know anything at all about laser beams?**

SUSAN **Well, it was in that James Bond film 'Goldfinger'.**

GILES **Yes—I remember the scene. James Bond was lying on a gold table, and the table was being cut down the middle by a laser beam.**

SUSAN **The idea was that it would eventually cut James Bond in half as well. Could it really do that?**

GILES **Oh yes! At least, a laser could cut the table.**

SUSAN **But not James Bond?**

GILES **Don't be so disappointed. So far, if my facts are up-to-date, the laser won't penetrate the body.**

SUSAN **But I thought they were using it to cure cancer?**

GILES **Experimentally. And, even so, it can only be used on skin cancer.**

SUSAN **But what is a laser beam? You say it's a beam of light. But there are beams of light from car head-lights, from pocket torches, from searchlights and so on. They don't do any of the things that a laser beam does. So what is special about a laser beam? What makes it different from the other beams of light?**

GILES **Well, light consists of waves. These waves are very short—much too short to see directly. And ordinary light consists of waves all out of phase, out of step, with each other. White light or sunlight is also a mixture of every possible wavelength. Waves of red light are about twice as long as waves of blue light. So white light is a mixture of all possible wavelengths, all out of step with each other.**

SUSAN **And what about laser beams?**

GILES **Well, first all the waves in a laser beam have the same wavelength. A laser beam has a very definite colour. The red colour of the ruby is one of the most widely seen colours in them. But the difference between an ordinary beam of ruby red light and a laser beam of ruby red light is that in the laser beam the waves are also all in step with each other. So compared with any ordinary beam of light, the laser beam is a very orderly affair indeed. It's like a military march—everyone in step. In an ordinary beam, the waves are like the people in a crowd going to a football match, jostling and bumping into one another.**

SUSAN **Does this orderly behaviour of the laser beam make a big difference?**

GILES **Oh yes, and there's one more difference. Most beams of light, like the car headlamp, for example, are continuous. They shine all the time. But the laser beam is intermittent, and it's off much longer than it's on. Because these switches on and off are very fast, the eye doesn't see them. While the laser beam is off the energy for the next flash is building up, and when it comes, it's a very intense flash indeed. So lots of power can be packed into a laser beam.**

SUSAN **Are there any other differences?**

GILES **Yes. An ordinary beam of light diverges. It gets wider and wider, and therefore dimmer and weaker as it goes on. But a laser beam doesn't diverge in this way. So it carries its energy in a compact form, until it's absorbed when it strikes something opaque.**

SUSAN **I see.**

GILES **So that's why a laser can drill holes in hard jewels, for example, industrial diamonds, and others used in machine bearings.**

SUSAN **Well, go on.**

GILES **A laser can punch holes in steel, or in the tough ceramics used in the interiors of jet and rocket engines. It can be used like radar to track satellites—and to map cloud structures or . . .**

SUSAN **That sounds marvellous. Anything else?**

GILES **Well, there is one interesting point. In spite of everything it can do, the pulse from the largest laser ever made doesn't contain enough energy to boil a kettle for a cup of tea.**

SUSAN **Is that some sort of a hint?**

GILES **It did occur to me that, among your other talents, you can boil a kettle and make a cup of tea.**

SUSAN **Well, since you've been so patient with me, Giles, I'll make you some. In fact, I'll even turn on the television for you again.**

GILES **Thanks!**

Lasers

To understand what a laser is, one has to understand how light is generated. Light comes from the electrons which surround the nucleus of every normal atom. When the atom, let us say, of sodium, is in its unexcited state the electrons which surround the sodium nucleus are in their normal energy levels and white. If this sodium atom absorbs some energy from outside, one or more of the electrons jumps from a low energy level or orbit to a higher energy level or orbit. The atom then remains in this excited state until it is able to release the energy it has temporarily stored. When this release occurs the electron in the high energy level falls back to the low energy level. But as it does so it emits the extra energy as a pulse which we may see as light.

Each possible jump of each of the electrons round the sodium nucleus has an exact amount or quantum of energy associated with it. When a number of sodium atoms are excited in the appropriate way they emit or absorb light of the same energy or colour. Sodium vapour has associated with it the famous D-line—a line in the yellow part of the colour spectrum which has a definite wavelength.

The word laser is an acronym—the letters of the word come from 'light

amplified stimulated emission of radiation'. The laser beam is made by exciting the atoms of a suitable material—ruby is one—until most of the atoms have electrons orbiting in a higher energy level than usual. The excitation is then stopped and all the excited electrons fall back together, to their normal orbits, each one emitting a pulse of light of the same energy. In this way an intense beam of light is generated for a very short time. And every pulse or wave-train in this beam is in step with every other pulse. In this way a beam of light is obtained which is both monochromatic and coherent.

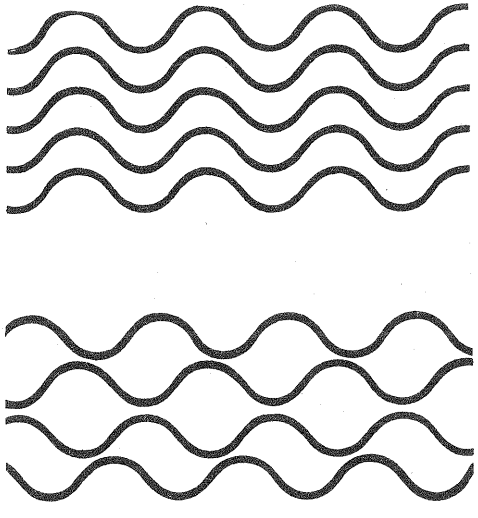


Fig. 1 — Coherent and incoherent beams

The word maser is also an acronym—for 'microwave amplified stimulated emission of radiation'. The maser is operated on the same principle as the laser except that the wavelengths generated are much longer and therefore the energy jumps involved are smaller. The excited bodies in a maser are molecules rather than atomic electrons and the beam generated is a coherent beam of microwaves which is not visible to the eye.

Laser beams carry surprisingly intense amounts of energy and so they can be dangerous to living tissue. The tissue absorbs the light in the beam and converts it into heat. If heat is generated in living tissues more quickly than it can be dissipated, then local heating of the tissue will occur. This local heating can be severe enough to kill the cells the beam impinges on. It is therefore necessary to protect the human eye, which is very sensitive to this kind of damage, when laser

beams are being used. The damage can be done very quickly, so protection from accident is very necessary.

By very careful control of the dosage of light energy in the flash of a laser beam the surgeon can perform operations on the human eye which are much more difficult to do than by other means, for example, in the case of damage to the retina.

The laser is a very useful tool for the sealing of tears in the retina of the eye which, if left untreated, might, in a large proportion of cases, lead to the detachment of the retina from the choroid. In effect, the laser beam burns together some cells of the retina and of the choroid and so the retina is, as it were, welded on to the surface to which it should adhere. The area affected is very minute, and as the weld is effected in perhaps 1/1000th of a second no general anaesthetic is needed, and no pain whatever is felt.

Lasers in Industry

Measuring lengths of a metre or so accurately has always been a problem to engineers. The conventional method is to take what are called length bars, that is, pieces of metal of fixed and accurate length—put them end-to-end and then make up the total length by adding slip gauges—slabs of metal of known thickness.

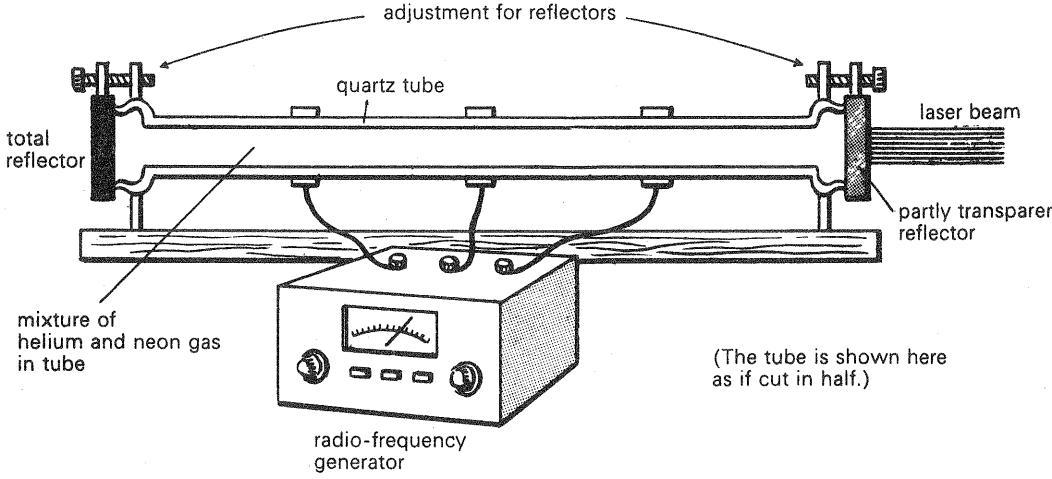

adjustment for reflectors
quartz tube
laser beam
total reflector
partly transparent reflector
mixture of helium and neon gas in tube
(The tube is shown here as if cut in half.)
radio-frequency generator

Fig. 2 — Gas laser

The trouble is that none of these is absolutely accurate and, of course, the errors accumulate when a number of items are added together in this way. Workers from the Ministry of Technology have found that, using length bars and slip gauges, a length of about 250 centimetres can only be measured to within an eightieth of a millimetre.

As engineering becomes more and more precise, better accuracies than this will be needed. So the technologists have turned to a new unit of length. It is the wavelength of light. Not any light, but the light emitted by a laser, a gas laser, containing helium and neon. This is really a sort of fluorescent tube—it glows with a rather attractive pale violet colour. The wavelength of the light is very constant, and is known quite accurately. By using well-known optical and electronic techniques, it is possible to count each distance of half a wavelength as you move along the laser beam. The beam acts as a ruler or yardstick, marked off every half wavelength, that is, about every three-thousandth of a millimetre.

This is fixed by the laws of nature, and in theory the laser yardstick could be made accurate to one part in a hundred million—that is, it could measure one metre with an error of one hundred-thousandth of a millimetre. But in practice Mother Nature is not quite so helpful. Variations in the temperature, pressure and humidity of the air through which the laser beam passes cause variations in the wavelength. The errors which arise as a result of this can be calculated, but of course there are also errors in measurement of the temperature, etc. and so the final accuracy is not nearly as good as the absolute theoretical accuracy. But it is still much better than when solid measuring bars are used.

Word Study

(1) vary
varied
variations
variety
various
variable

Variations in the temperature, pressure and humidity of the air through which the laser beam passes cause *variations* in the wavelength.

Daily and seasonal *variations* in the solar radiations lead to *variations* in atmospheric temperature and pressure.

The pattern of winds is therefore continuously *variable.*

Plastics are manufactured in a *variety* of forms.

The D.L.I.S. receives regular reports in *various* countries.

Engineers use *various* methods to reduce fluctuation in demand.

Most *varieties* of steel contain elements such as carbon, silicon and phosphorus.

(2) measure
measuring
measured in
measurement
measurable

A simple piece of apparatus delivers a *measured* volume of insecticide on to the locust.

Lasers can be used as *measuring* instruments for making accurate *measurements* of very small objects or displacements.

The enormous distances of galactic space are usually *measured* in terms of the light-year which is the distance light travels in one year.

(3) to impinge
impact

According to the law of momentum, when two elastic particles *impinge* the total momentum before *impact* equals the total momentum after *impact.*

(4)	to emit	emission
	to transmit	transmission
	to absorb	absorption

The light *emitted* from the glowing filament of an electric lamp has a wide range of wavelengths; it is polychromatic.

The *emission* of light from a laser occurs at one definite wavelength characteristic of the laser; it is monochromatic.

Light is *transmitted* by transparent materials such as glass but is either *absorbed* or reflected by opaque materials.

(5)	to excite	excitation

When one ore more of its electrons jumps to a higher energy level, an atom is said to be *excited.*

The energy of *excitation* of an atom is released by the emission of light.

(6)	to phosphoresce	phosphorescent
	to fluoresce	fluorescent

Phosphorescent materials glow in the dark because chemical energy within them is being converted directly into light. Certain fishes and insects *phosphoresce* in this way.

In *fluorescent* materials energy previously absorbed is emitted again as light.

11. Statistics

Giles and Susan Newton are talking to a statistician, Dr. John Engleton.

SUSAN NEWTON **Dr. Engleton, don't you think 'statistics' is a rather overused word these days?**

GILES NEWTON **Really, Susan, what a way to start talking to a statistician! But the word 'statistics' is surely a much abused one, Dr. Engleton?**

DR. ENGLETON **Yes, that's true, Mr. Newton, but there's some misunderstanding of what statistics are. If you measure things, then you get sets of figures that might be called statistical data. But statistics also have a theory, which is based on the theory of probability.**

SUSAN **Theory of probability. Oh dear, I'm not quite sure I understand!**

DR. ENGLETON **Well, modern statistics consist of two main strands, a technique for collecting, summarizing and analysing data: that's descriptive statistics.**

SUSAN **That's the first strand!**

DR. ENGLETON **Yes. And applied probability theory: theoretical statistics.**

SUSAN **That's the second strand!**

GILES **But what is the subject of descriptive statistics?**

DR. ENGLETON **Well, if you collect statistical data, the first thing you have to do is to arrange them compactly and systematically. For example, if you were to measure and tabulate the heights of all the men over the age of twenty-one who live in London, you'd be able to say how many of them had heights of 150 to 155 centimetres, or of 155 to 160 centimetres and so on. You could also say what the average height of these Londoners is.**

SUSAN **I can see that. But isn't that a rather useless exercise? Who wants to know?**

GILES **Oh, it's not useless at all, Susan. The manufacturers of ready-made clothing want to know what sizes of clothes, and how many of each size, they should make.**

DR. ENGLETON **That's quite true. And manufacturers of cars like to know how many customers they will lose if they design cars which are**

uncomfortable, let us say, for drivers who are taller than 160 centimetres. So data of this kind can be valuable. The standard deviation of the heights is also very useful.

SUSAN I know what you mean by the average height. But what do you mean by standard deviation?

DR. ENGLETON Well, the standard deviation of a set of numerical data is a measure of the spread of the data. It could be explained more clearly in this way. For example, London is a cosmopolitan city, with people from many countries, some from countries where men are less tall than the average height in Britain. So I would expect the height of men living in London to be rather widely distributed, to have a rather large standard deviation.

GILES But if we were to separate the men living in London into their separate national groups, we would expect the groups to be more homogeneous: some of relatively short men, some of relatively tall men.

DR. ENGLETON Yes, indeed, and these distributions would have different averages and smaller standard deviations than the total groups of all men living in London.

SUSAN I think I see now what a standard deviation tells you. But it still all seems to me a bit useless—just numbers for the sake of numbers!

DR. ENGLETON Oh no, that isn't quite true. There is something more about sets of numerical data like heights of men from different countries. All these sets have a similar distribution.

GILES By that you mean that most men will be of average, or nearly average, height?

DR. ENGLETON Yes, and there are smaller numbers of men who are much taller or much shorter than the average. And all these numbers have the same pattern, which can be represented by the same mathematical equation or graph.

SUSAN A graph. Oh, yes, you mean a diagram showing numbers horizontally and amounts vertically.

DR. ENGLETON Yes, indeed, that's one kind of graph. I've got here some examples of the normal distribution. You'll notice that they are all symmetrical. They rise to a maximum at their centres, you see, and fall away to zero on both sides.

SUSAN Oh, yes. They look like hills or mountains.

DR. ENGLETON This particular distribution is called the normal distribution. It seems to arise when any given basic quantity is liable to be

affected by many random factors. Some of these factors increase the basic quantity, others decrease it. Some act one way, some the other. When I know that the heights of men conform with this law, then the only two figures I need are the average and the standard deviation.

GILES You can then throw away the detailed data, because you can calculate anything you want from the two key figures.

DR. ENGLETON Exactly. So by this means, I can actually dispense with many numbers.

SUSAN I hadn't appreciated that descriptive statistics could help you reduce the amount of data! That is your point, isn't it?

DR. ENGLETON Yes, it is. It does astonish most people to find that random processes can in fact be accurately described. Statisticians sometimes talk of the 'laws of chance'. But to many people this seems to suggest a contradiction, because they think that chance is something random or without law.

GILES What about a single event like the tossing of a coin? That's a random event, isn't it?

DR. ENGLETON Yes, it is. We know, because we've tried it, that if you continue to toss a penny, the ratio of heads to tails becomes closer and closer to one. It's very unlikely that the number of heads will exactly equal the number of tails. But I can calculate how different the number of heads and the number of tails are likely to be. Again it's because I know the form of the distribution of all possible results of tossing a coin many times. One can calculate the mathematical form of this distribution by applying probability theory.

SUSAN Oh, yes. Now I see what you meant earlier by applied theory.

DR. ENGLETON Full marks! I think your wife is a statistician already, Mr. Newton.

Statistics

It is possible to prove that as the number of tosses of a coin is increased indefinitely, or 'to infinity', so the binomial distribution becomes identical with

the normal distribution. For each kind of random event there is an underlying distribution. The normal or gaussian distribution is very important because it arises very often in practice and also because it is very important in theory. Many distributions like the binomial tend to become more and more like the normal as the numbers of events or the size of the sample increases.

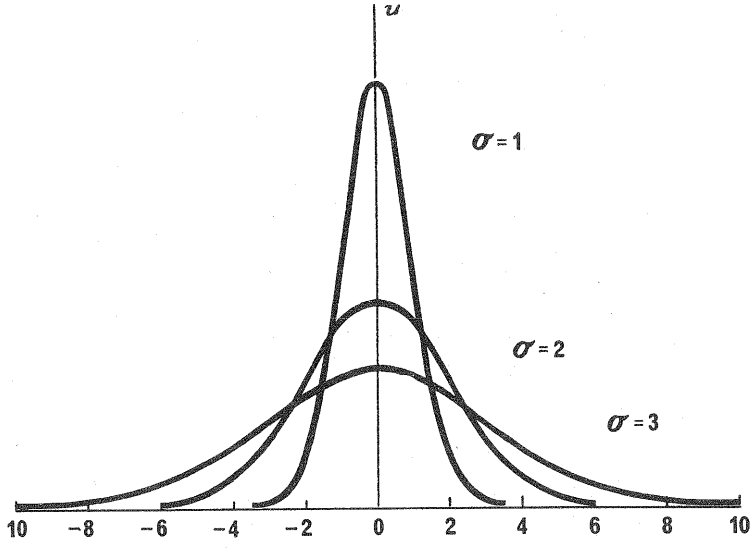


Fig. 1 — Normal curves with different standard deviations

The diagram shows three examples of the normal distribution. Each normal distribution has the same mean—zero, but they have different standard deviations or different degrees of spread or dispersion.

Another well known statistical distribution is the Poisson distribution. If we are dealing with the frequency of occurrence of events which occur at random in time or space, we should expect the Poisson distribution to play some part in the calculation. For example, during office hours a man may find that he gets on average three calls per hour. That does not mean that he gets a call every twenty minutes, or three calls in every hour. Some hours are so quiet that he gets no calls at all; some are so busy that he gets six or eight calls in the hour. But the average is three. The probability of getting an hour free of telephone calls is one-twentieth, and the probability is that only one hour in twenty will be wholly free of calls. The probability of getting only one call in the first hour is one-seventh.

In this example the results are not of much practical importance. But the Poisson distribution—the randomness of telephone calls—has to be taken into

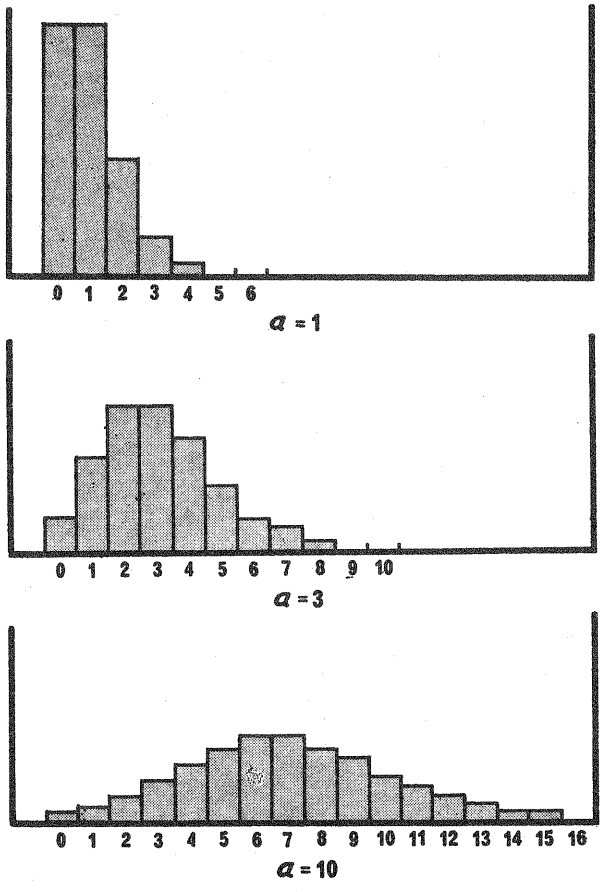


Fig. 2 — Poisson distribution for different values of a

account by those who design telephone systems or telephone exchanges. In fact the Poisson distribution is a key to the design of all systems which involve random actions like the making of a telephone call. So it is the basis of 'queueing' theory. How many service points shall be provided at a garage, at a post-office, at a railway station, at an airport, for a spare parts or components service, for efficient use of staff and effective services for the customers when the average level of the demand for services is known? The Poisson has many practical applications in the design of efficient or economic services on which demands are made at random.

The second diagram shows some examples of the Poisson distribution. The

only feature they have in common is that all of them eventually fall away to zero.

But you will have noticed that the graphs of the normal were smooth curves whereas the graphs of the Poisson distribution are stepped columns we call histograms. This is because the normal distribution is concerned with continuous quantities, that is, with quantities one can measure. For example, the height of man is a quantity one measures as 160·352 centimetres, depending on how exact you want to be. The Poisson distribution on the other hand is concerned with discrete quantities, that is, with quantities one can only count: 0,1,2,3 . . . For example, the number of children in a family is a discrete quantity, a number one counts: 0,1,2,3 . . .

Word Study

(1) finite
infinite
definite
indefinite

The binomial expansion of $(q + p)n$ is *finite* when n is an integer; the number of terms in the expansion is $(n + 1)$.

The numerical sequence 1,2,3,4 . . . can be continued *indefinitely*, without limit; such a sequence is *infinite*.

As the value of x tends to c, the value of the expression $\frac{x - c}{x^2 - c^2}$ tends to 0/0, which is *indefinite*. But if the common factor $(x - c)$ is first cancelled, the fraction reduces to $\frac{1}{x + c}$ and its value tends to the *definite* value $1/2c$ as x tends to 1.

To a pure mathematician concerned always with exact *definite* quantities, the probabilistic estimates of the statistician always look very *indefinite*.

(2) continuous
discrete

Statistical variables may be either *continuous* or *discrete*: continuous variables, such as lengths, are usually measured; *discrete* variables, such as numbers of people, are usually counted.

(3) frequent
frequency
frequently

The *frequencies* of publication of scientific journals vary widely; some are published weekly, some monthly and some only four times in the year.

The *frequency* of the alternating current supplied to this radio set must be 50 cycles per second.

The set of statistical tables in my office is needed for *frequent* reference.

When I am tired I *frequently* make silly arithmetical mistakes.

(4)
probable
probability
possible
possibility

The *probability* that a tossed coin shows 'heads' in n successive throws is $(1/2)n$.

It is *possible* that all the telephone subscribers on this exchange will try to telephone simultaneously but, fortunately, it is highly *improbable.*

It is incorrect to say that perpetual motion without absorption of energy from some source is *improbable*; it is *impossible.*

to distribute	distribution
to disperse	dispersion
to deviate	deviation

In a lottery the probability of success should be *distributed* uniformly over all the legitimate possibilities.

The heights of adult men are found to conform with the normal or gaussian *distribution.*

The standard *deviation* is a measure of the degree of *dispersion* of a variable about its mean value. The more widely the variable is *dispersed*, the greater is its standard *deviation.*

12. Telecommunications

Giles Newton has been asked to prepare an article on telecommunications. To learn more about the subject, he and Susan visit two friends, Andrew Smith and Paul Huntley, who work in the laboratory of a company that develops and manufactures various types of communications systems.

SUSAN NEWTON **Andrew, how would you define 'telecommunications'?**

ANDREW SMITH **The sending and receiving of information by electrical means.**

GILES NEWTON **Well, that's simple enough.**

PAUL HUNTLEY **Yes, but that is where simplicity ends, Giles. The modern telephone exchange, for example. We take it pretty much for granted, yet it automatically connects all stages of local and long-distance calls, and can handle several thousand conversations during precisely the same second of any time of any day.**

ANDREW **The interesting thing is that the more complete telephone services become, the more the demand for those services grows.**

PAUL **Yes, and it's those increased demands that lead to some of the problems we have to solve in improved methods of carrying messages or signals.**

ANDREW **Radio was used for long-distance telephone services as long ago as the 1920s for linking the continents across the oceans.**

PAUL **The radio telephone terminals were located outside the big cities and linked to them by lines.**

GILES **I suppose in those early days signals had to be picked up, received, outside the cities, because in cities they have the problem of atmospherics, or what most people call 'static'.**

PAUL **Yes, well we get round that today by using H.F., that's High Frequency—any frequency from 3,000 to 30,000 kilocycles per second. And V.H.F., Very High Frequency; and U.H.F., that's Ultra High Frequency.**

ANDREW **And it's these higher frequencies that are, for all practical purposes, clear and static-free.**

SUSAN **I see.**

PAUL And just to keep the record straight, there's the S.H.F., the Super High Frequencies, ranging from three million to thirty million kilocycles per second. And it all adds up to a very tiny window in the electromagnetic spectrum.

SUSAN Electromagnetic spectrum?

PAUL Yes, that includes radio waves and light waves, the whole range.

ANDREW And, of course, radio is used for ship-to-shore and ground-to-air communications which can be telephonic, using the voice; or telegraphic, using morse code or some other pulse system.

PAUL Yes, and incidentally, the S.H.F. wasn't possible until the early 1950s, and the development of two new valves that could generate and amplify these exceedingly high frequencies.

ANDREW If you want to make a note of it, the generator valve is called the klystron, and this was followed by the travelling wave tube for amplification.

GILES I see. Together they made possible the use of the Super High Frequencies.

ANDREW Right! And with S.H.F. we can transmit eighteen hundred messages—telephone conversations, for example—in a single radio channel simultaneously.

SUSAN We're always hearing about microwaves. Where do they fit into this arrangement of frequencies?

ANDREW The microwave is transmitted on the S.H.F. However, I'd say its use is both a blessing and a curse.

SUSAN Oh, come on, Andrew! You can't make a statement like that, and just leave it there!

ANDREW Well, first you must understand that microwaves behave similarly to visible light.

GILES You mean they travel in straight lines?

PAUL More or less.

SUSAN Is that a disadvantage?

PAUL Not when we're transmitting to satellites or spacecraft. But from point to point on this planet, we're limited by the curvature of the earth's surface.

ANDREW In other words, our transmission distance extends up to about twenty-five to thirty miles, depending on the height of the receiving point or relay-station.

SUSAN So that's why the Post Office Tower in London has to be as high as it is?

ANDREW **Yes, the top is six hundred and twenty feet above the streets of London—the tallest building in Britain.**

GILES **What is the actual present capacity of the Tower?**

PAUL **It can send out one hundred and fifty thousand telephone calls simultaneously.**

ANDREW **Or it could relay one hundred television programmes all at once.**

PAUL **In fact, of course, the facilities are shared between telephone, television, teleprinter and other signals.**

ANDREW **But you still don't have the complete story.**

GILES **You mean satellites? I'd like to hear about them.**

PAUL **Well, do you know what a stationary satellite is?**

GILES **Yes, it's in orbit, and it's made to travel at such a speed that it remains in the same position relative to the earth.**

PAUL **Yes, and it can 'see' one-third of our planet.**

ANDREW **Therefore three of them can provide uninterrupted 24-hours-a-day global communications all round the world. The signal—telephone call, television programme or what-have-you—is beamed to a stationary satellite by microwave.**

GILES **And relayed by it to a ground station.**

SUSAN **So the volume of telecommunication traffic through a satellite depends on the number of ground stations it can reach, and its capacity. The newest satellites can carry a thousand telephone conversations and a colour TV programme simultaneously.**

GILES **Susan! You've been reading again!**

Wires and Cables

Ever since the introduction of the telephone, there have been new problems arising from the carrying of signals or messages. At first, each signal was carried by means of a pair of overhead wires. Telephone exchanges were soon surrounded by thousands of wires. The wires were then replaced by cables, each containing many pairs of wires and therefore capable of carrying many signals. These cables, laid underground, replaced the overhead wires.

The more extensive telephone services have become, the more the demand for

these services has increased, particularly the demand for long-distance services. In the United Kingdom this growth of traffic is now about 17% per annum. Long-distance telephone exchanges are usually located in crowded cities, where it is costly and inconvenient to lay new cables for expanding services.

Radio Links and Microwaves

The use of radio to relay telephone signals and to link exchanges makes it possible to dispense with overhead wires and some underground cables.

In a microwave system the separate input messages from various sources must be brought together to give a composite input which is then transmitted and received by radio. The composite signal received must then be split into its original components, enabling the input messages to be switched to their various destinations.

Telecommunications engineers have developed several techniques which permit simultaneous messages to be compounded, transmitted, received and separated again. All the techniques rely on the fact that a microwave beam consists of a band of radio frequencies, just as a beam of white light is composed of the whole spectrum of colours from red to violet which could be used separately for signalling. The total radio bandwidth available for the channel is sub-divided into a number of equal sub-bandwidths. Each separate bandwidth provides a separate radio channel as though it were a single pair of wires in a cable of many wires.

The frequencies of microwave signals are very much higher than those needed for the transmission of intelligible speech, which requires a frequency bandwidth of only two or three thousand cycles per second. So the super high frequency

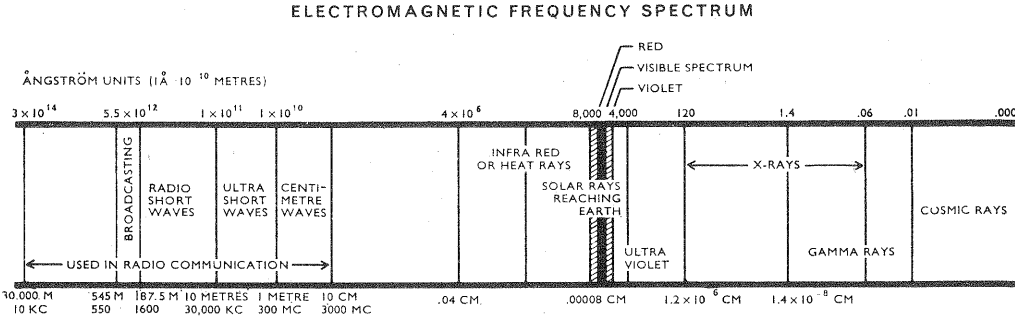


Fig. 1

radio wave of each separate microwave channel is used as a carrier wave which is modulated to transmit the signals. At the receiving end the modulated carrier waves are amplified and converted back to the modulating speech frequencies.

The number of separate sub-bandwidths available in any radio channel is proportional to the total bandwidth of the channel and increases as the mean frequency of the channel increases. Microwave beams, having frequencies of the order of 3×10^{10} cycles per second, can accommodate the very large number of sub-bandwidths required for separate channels and may permit up to 1,800 messages to be transmitted simultaneously in a single channel. So that they can be fed into the microwave transmitters, individual telephone signals are combined into groups and a number of groups and thus into a composite signal, which is fed through hollow waveguides to the aerials.

RADIO FREQUENCY CLASSIFICATIONS

Frequency in Kilocycles per Second	Designations	Abbreviations
10 – 30	Very Low	VLF
30 – 300	Low	LF
300 – 3,000	Medium	MF
3,000 – 30,000	High	HF
30,000 – 300,000	Very High	VHF
300,000 – 3,000,000	Ultra High	UHF
3,000,000 – 30,000,000	Super High	SHF

Fig. 2

Microwaves behave in much the same way as visible light, travelling in straight lines. Parabolic dish and horn-shaped aerials use reflectors to focus the microwaves into narrow parallel beams. These aerials both transmit and receive signals.

The Post Office Tower in London is the centre of a microwave network of 126 stations. The total capacity of the Tower is 150,000 simultaneous long-distance telephone calls. But the Tower can also relay television signals, 100 channels if used for television alone. In practice, the facilities are shared between telephone, telegraph, teleprinter and other signals. The circular aerial galleries are designed to provide microwave routes in any direction. The aerials, placed high on the Tower in order to clear all obstacles, transmit microwave signals to relay stations about 45 kilometres away. The aerials of all the relay stations have to be carefully aligned so that the narrow beams will not miss their mark.

International and inter-continental telecommunications are now made easier

by using satellites to relay microwave signals over many thousands of kilometres.

Unfortunately cables and microwave radio links cannot be exploited so effectively for long distance paths across the oceans. Firstly, submarine telephone cables cannot provide the wide bandwidths attained by similar inland cables (this is because all the repeaters in the cable must receive their power supplies from the shore), and secondly, microwave radio beams travel in straight lines and are boosted by repeaters, as already mentioned. To pass signals round the curve of the earth, a transatlantic radio path using microwave frequencies would need a floating repeater every 30 miles, or, one station with a tower nearly 500 miles high! Even aeroplanes and balloons cannot fly as high as this, but satellites can.

Satellites

A new aerial system at the Post Office's Goonhilly Earth Station, in Cornwall, in the south of England, has been swung into action, after the successful launching of an Intelsat III satellite over the Atlantic Ocean. Called Goonhilly 2, the giant aerial, 90 feet in diameter, will maintain a leading role in space communications which has already been firmly established by Goonhilly 1's pioneering work with the Telstar and Early Bird satellites.

Intelsat III has been put into an equatorial orbit 22,300 miles above the earth so that it hovers over the Atlantic Ocean between Europe and America.

Early Bird provided a single transatlantic link for not more than 240 telephone conversations or one television programme. Intelsat III can provide a multiplicity of links between earth stations in Europe, Africa and the American continent. This new system can carry 1,000 telephone conversations and a television programme simultaneously. Initially, Goonhilly 2 will carry large groups of telephone calls to earth stations in the U.S.A. and Canada. Services are expected to be opened to Morocco, Nigeria and Iran.

Now that greatly increased traffic capacity is being provided by the new aerial, Goonhilly 1 will no longer be required for the service to America. It is being provided with new equipment to enable it to operate with countries to the east of Britain via an Intelsat III satellite to be positioned over the Indian Ocean. This new satellite together with three other Intelsat III satellites, two over the Atlantic Ocean and one over the Pacific Ocean, will provide a global system of communications.

The new installation at Goonhilly provides easy access to all the very sophisticated apparatus required at a modern earth station. A high degree of

automation and self-checking is provided, and in the comparatively rare event of a fault, the apparatus can be attended to without interruption of service.

Goonhilly 2

The aerial makes use of a Cassegrain configuration with a spinning horn at the apex of the main reflector. The spinning feed-horn is a feature of Marconi's 'mode conversion scanning system' of aerial steering. It introduces a conical scan of the aerial beam only at the frequency of the satellite beacon signal. Thus it avoids unwanted amplitude modulation of the communication carriers or significant degradation of aerial efficiency for either direction of transmission. By this means auto-tracking can be achieved either by servo control of the main

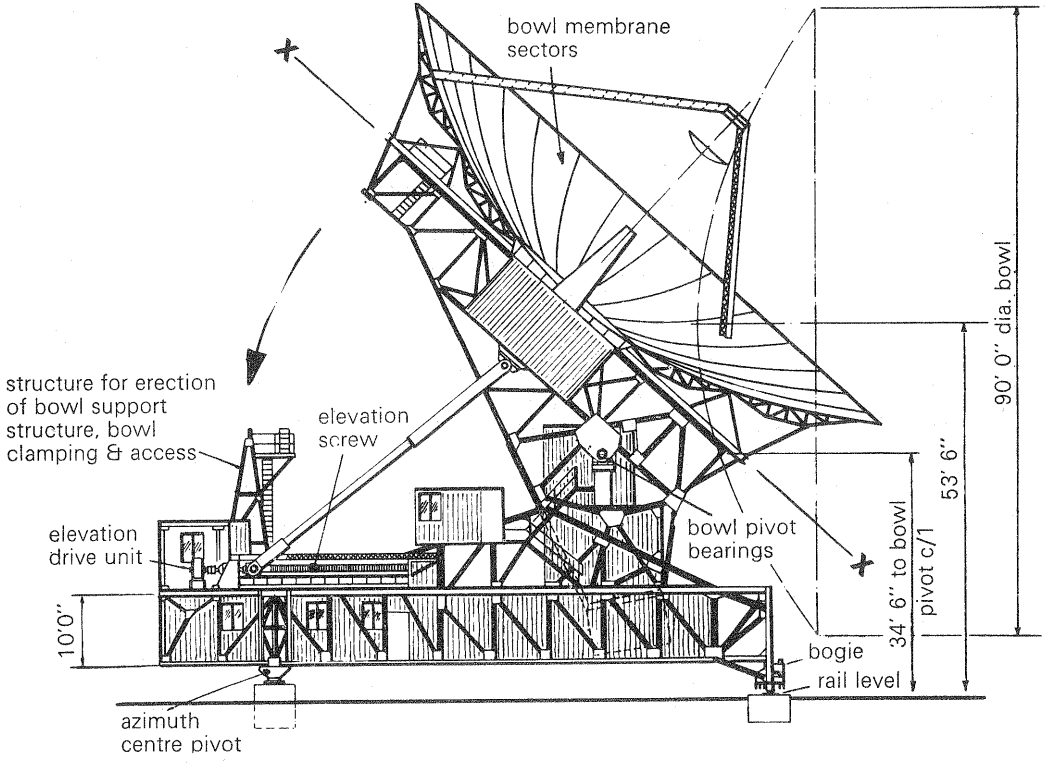


Fig. 3 — Goonhilly 2

reflector mounting or, within a range of about ±20 minutes of arc, by deflection of the sub-reflector. Provision has also been made for control of the aerial manually and for the addition of tape control facilities later, if required. Motor-driven bogies running on a circular track rotate the whole aerial about a central pivot and tilting of the reflector about its low level elevation axis is controlled by a single horizontal screw and cross-head linked by a massive connecting rod to the upper part of the strong back of the reflector. Both driving mechanisms are powered by duplicated thyristor-controlled DC motors operating via differential gearboxes.

The aerial and telecommunications equipment are controlled and monitored from a suite of consoles in the central building. Each carrier, which may transmit up to 132 telephony channels, is monitored separately and reserve equipment is switched into use automatically if a disabling fault condition arises. Faults which cause degradation of the service but do not interrupt it can be located and eliminated by manual switching of their component sub-systems without interference with traffic. A separate console enables the television service to be monitored and tested.

A microwave radio link from Goonhilly extends the satellite circuits to the International Telephone Services Centre in London. In the central building at Goonhilly, the circuits are re-arranged at baseband frequencies into units of 24, 60 or 132 channels as dictated by traffic requirements.

Also injected into the circuit at this point are a 60 KHz continuity pilot, an energy dispersal signal to restrict the level of intermodulation products during light traffic loading and engineering service channels at sub-baseband frequencies. Inter-site coaxial cables transmit the modulated I.F. carriers to the equipment on the aerial where they are converted individually to their assigned frequencies in the GHz band. All carriers are then combined at low power level before amplification, in two stages, by common wideband travelling-wave-tube amplifiers. The output stage has a maximum CW capability of 8–10 KW but in order to restrict the power of unwanted intermodulated products it will not normally be loaded above 1·5 KW. A second transmitter, which serves as a reserve for the telephony system, can be used alternatively for television transmissions.

The very weak signals from the satellite in the 4 GHz band are amplified by a three-stage parametric amplifier, cooled to 16°K in a closed-circuit, gaseous-helium refrigeration system followed by a tunnel-diode amplifier. The four stages have an overall gain of 40 dB over the 500 MHz frequency band assigned for the down path from the satellite. The effective noise temperature of the amplifier, referred to its input, is less than 20°K. At the output of the common amplifier the individual carriers are separated by a selective branching network, converted

in frequency to 70 MHz and extended individually by coaxial cables to the FM feed-back demodulators in the main building. Here, supervision is effected by monitoring the synchronizing pulses.

Extensive provision of switched redundant equipment in the system and the comprehensive control facilities will ensure a high standard of reliability and enable maximum economy of operational manpower to be achieved.

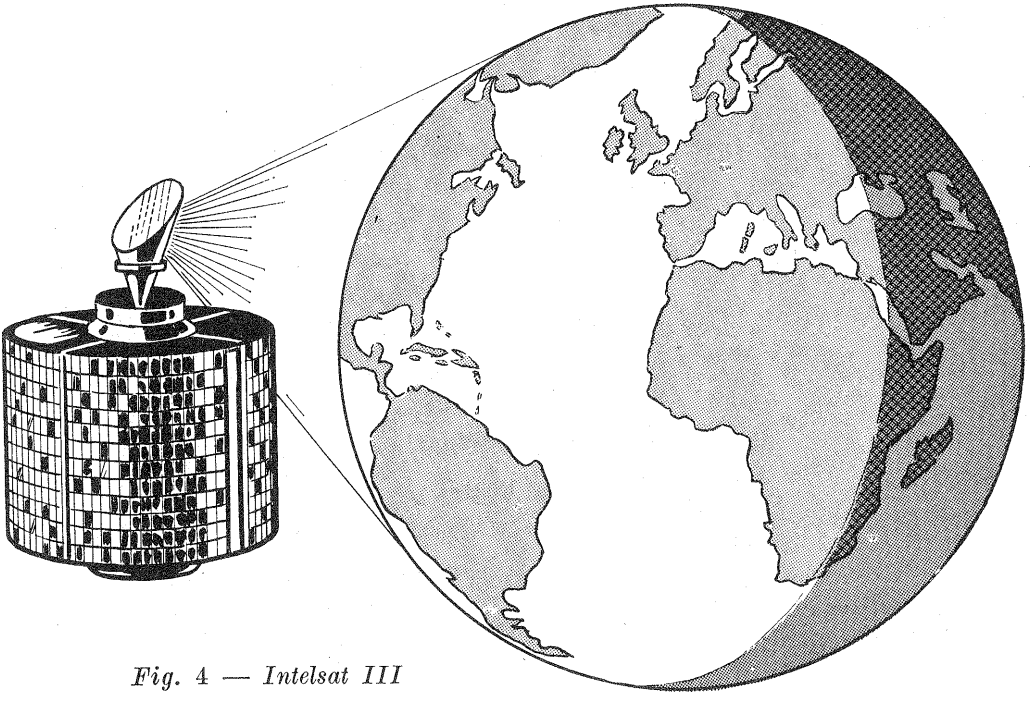


Fig. 4 — Intelsat III

Word Study

(1) *to amplify*—to make larger

amplify
amplifier
amplification

This *amplifier* has a gain of about 10.
The *amplification* of the signal must be achieved without distortion.

(2) *to compose*—to put together, assemble

compose
composition
composite

The component parts of the *composite* signal have to be separated again.

(3) *to extend*—to stretch out

extend
extensive
extensible
(extent)

The aerial normally has a length of 1·5 metres but is *extensible* to 2·5 metres.
The range of the local relay station is being *extended* from 10 to 15 km.
The *extent* of the damage is being assessed.

(4) *to align*—to put in line

align
alignment

The horn aerials are *aligned* along the line of sight.
If they are in *alignment*, signals can be received; if they are *out of alignment* they cannot.

(5) to multiply
multiplication
multiple
multiplicity

The result of *multiplying* 3 by 7 is 21.
The *multiplication* of 3 by 7 yields 21.
The smallest *multiple* of 3 and 7 is 21.

The separate insulated wires are wound together to form a cable with a *multiple* core.

A single frequency band can accommodate a *multiplicity* of operating channels.

(6)		
	to deflect	deflection
	to reflect	reflection
	to refract	refraction

The windscreen of a moving car *deflects* the air-flow over the driver's head.

When one looks at a *reflection* in a plane mirror, the image appears to be as far behind the mirror as the object is in front.

Light is *refracted* when it passes from one medium into another of different density. The angles of incidence and of *refraction* are related by Snell's law.

The gravitational field of the sun causes a *deflection* of any beam of light which passes near the sun.

The Metric System of Weights and Measures

At the time of going to press, industry in Britain is changing to the metric system of weights and measures. The change is gradual, and as the imperial system based on the standard yard and the standard pound weight are still in use, metric equivalents have not been given in the recorded conversations.

The relationship between some imperial units and corresponding metric units are given below.

Length

1 millimetre (mm) = 0·03937 inch (0·03937″) (about 40 thousandths of an inch)
1 metre (m) = 39·37 inches
= 3·28 feet (3·28′)
= 1·0936 yard
1 kilometre (km) = 3,281 feet
= 0·6214 mile (about $\frac{5}{8}$ mile)

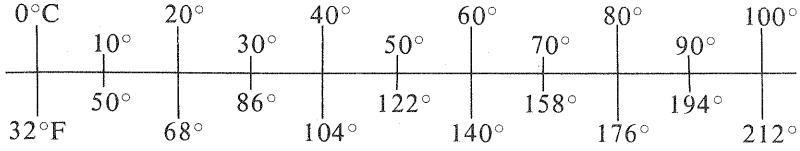
Weight

1 gram (g) = 0·0353 oz. (ounce)
1 kilogramme (kg) = 2·2046 lbs. (pounds)
1 tonne (t) = 1,000 kilogrammes
= 2,204·6 lbs. (about 1 imperial ton)

Volume

1 litre (l) = 1 cubic decimetre (dm^3)
= 1·76 pints
= 0·22 gallons
1 cubic metre (m^3) = 35·315 cubic feet
= 1·308 cubic yards
= 220 gallons

Temperature



0°C is the freezing point of water
15°C is the temperature on a warm spring day
30°C is the temperature on a very hot summer's day
37°C is the normal body temperature
100°C is the boiling point of water

Pronunciation of Simple Equations and Scientific Formulae

Notes

The text below is recorded, with pauses for repetition.

(i) It is important to observe the phrasing or grouping of expressions. The pauses between the groups are indicated in the following examples by a comma.

(ii) Formulae in brackets. In reading formulae in which terms are grouped together within brackets it is usual to pause slightly just before and just after the group.

The word *bracket* would not be actually spoken in scientific discourse if the formulae could be seen in print or on a board.

(iii) The names of the letters of the English alphabet constantly recur, so it is necessary to make sure to pronounce these correctly.

A practice band for these, and the most commonly used Greek letters, is included on the accompanying recordings.

The reading of some of the formulae can have acceptable alternative versions.

Section one

31%	thirty one per cent
30·7°	thirty point seven degrees
0·631	nought point six three one
$+3\frac{1}{2}$	plus three and a half
$-5\frac{1}{4}$	minus five and a quarter

Section two

$\frac{1}{x}$	one over x
y^2	y squared
k^3	k cubed
$3a^4$	three, a to the four
$\frac{\alpha^5}{\beta^2}$	alpha to the five, over beta squared

Section three

$\sqrt{x}$	root x *or you could say:* the square root of x
$\sqrt[3]{y}$	the cube root of y
$\sqrt[4]{z}$	the fourth root of z
$\frac{1}{\sqrt{x}}$	one over root x
$\frac{1}{x^n}$	one over x to the n

Section four

$e = mc^2$	e equals, mc squared
$r = \frac{R}{n}$	little r equals, big R over n
$xX + yY = 1$	little x, times big X, plus little y, times big Y, equals one
$y = Ax^2 + Bx + C$	y equals, A x squared, plus B x plus C
$\frac{x}{X} + \frac{y}{Y} = \frac{z}{Z}$	little x over big X, plus little y over big Y, equals, little z over big Z

Section five

$x = 3(a + b)$	x equals three, bracket a plus b, bracket
$y = \frac{(a + b)}{3}$	y equals bracket a plus b bracket, all over three
$y = a + \frac{b}{3}$	y equals a, plus b over three
$y = 3\{x(a + b) - k(a - b)\}$	y equals three, curly bracket x, bracket a plus b bracket, minus k, bracket a minus b bracket, end of curly bracket
$y = (x^2 + a^2)(x^2 + b^2)$	y equals, x squared plus a squared, times, x squared plus b squared

Section six

$\log_{10} 7$	log of seven to the base ten
$\log_e n$	log of n to the base e
$\log (a + b)$	log, a plus b
e^x	e to the x
$e^{-x^2/2}$	e to the minus x squared over two

Section seven

$Ca(OH)_2$	C a, O H twice
$(CH_3)_2CO$	C H three twice, C O
$C_6H_4(OH)_2$	C six H four, O H twice

Section eight

$\frac{\pi}{2}, \frac{\pi}{3}, \frac{\pi}{4}$

$\tan \theta = \sin \theta / \cos \theta$

$\cos (\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta$

$\sin {}^2\lambda + \cos {}^2\lambda = 1$

Section nine

$\bar{x} = (x_1 + x_2 + x_3)/3$

$\sigma^2 = ({x_1}^2 + {x_2}^2 + {x_3}^2)/3$

$$\frac{xx'}{a^2} + \frac{yy'}{b^2} = 1$$

$(1 - x)(1 - y)(1 - z) = 1 - x - y - z + xy + yz + zx - xyz$

Section ten

As $n \to \infty$, $\left(1 + \frac{1}{n}\right)^n \to e$

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots + \frac{x^r}{r!} + \ldots \text{ to infinity}$$

If $x = \alpha t + \beta$, then $\frac{\Delta x}{\Delta t} \to \alpha$ as $\Delta t \to 0$

$$\log (1 + x) = x - \frac{x^2}{2} + \frac{x^3}{3} \ldots \text{ only if } |x| \leqslant 1$$

Structures of Scientific English

The parts of the dialogue on page 8 which are directly concerned with corrosion and the whole of the written passage which follows are in a style which is very far removed from the kind of English usually recommended in English language textbooks.

In their work, scientists and engineers wish to communicate primarily with other scientists and engineers. Normally they do not need to make the subject they are dealing with seem interesting or exciting, since they are writing or talking to those who have chosen to read or listen. So their way of saying things may lack variety. They are far more concerned with being accurate and concise, and they want to avoid any sort of misunderstanding. One way of achieving all these objectives is to use universally accepted symbols and formulae, like the symbols in the written passage on page 9. Symbols and formulae cannot be used all the time, but even when they communicate wholly or partly in words scientists and engineers employ a formalized way of expressing themselves.

A working example is customarily introduced by the following formula:

> Consider a high pressure chamber.
> Imagine a charge of gas to be compressed inside the chamber.
> Let P_1 be the initial pressure.

The purpose or function of a process or thing is often put at the beginning of a sentence:

> To determine the number of cells, a sample is put under a microscope.
> To increase the rate of reaction, a catalyst is used.

Very commonly statements are compressed by omitting words or parts of a sentence, or by using standard abbreviations. For example:

> In the form in which they have been presented, the figures give no useful information.

This might be shortened to:

> Thus presented, the figures give no useful information.

Another example:

> The results of this experiment show that AMX significantly impairs the co-ordination of hand and eye.

This might be shortened to:

> The AMX results show significant hand/eye co-ordination impairment.

Conventions like these are reinforced by the repeated use of sentence patterns which reflect the impersonal, objective attitude referred to in the previous section. For instance, the results of experiments and research may be introduced by phrases beginning with *it* and using the passive:

> It was found that the rate of flow was improved by increasing the pressure.
> It has been shown that these specimens can only be preserved if kept at a temperature of 34°C.

An important and perhaps surprising feature of technical English is that its formal style is common to both written and spoken communication. In the spoken passage on page 8, for example, the style changes abruptly from informal conversation to formal talk about a technical subject. Much of the communication between scientists or engineers has always been carried on in writing, and when they *speak* as specialists, they naturally adopt the *written* forms of technical English. Unless a scientist or engineer is being deliberately informal, he will tend to '*speak like a book*' when he is discussing his own subject. But of course a scientist is also a social person. So you will hear scientists speaking personally and informally when they are being sociable, and impersonally and more formally when they are being scientific. The contrasts between these two styles illustrate how the English of science and technology differs from the English of literature and of everyday life.

The formal style of technical English may cause difficulty at first to anyone who is not accustomed to it, and its conventions are admittedly sometimes used when they are out of place. But it greatly assists effective communication between scientists and engineers. Of course, when he is explaining a technical subject to a non-specialist, an expert will want to keep what he is saying as simple as possible. Indeed, much of the dialogue which is included in this book is of this sort. But it still contains many examples of the formal style which comes naturally to a trained scientist or engineer whenever he is dealing with technical matters.

The Passive

1. PERSONAL AND IMPERSONAL SENTENCES

A. We built the bridge. B. The bridge was built.

Sentence A is personal. It tells us *who* did something.
Sentence B is impersonal. It tells us *what* was done.

Notice that the sentence B does not mention people and that it uses the *passive*: was built.

Scientists prefer to use impersonal sentences of this kind when they talk or write about their work, because they should always try to be objective about any scientific activity.

Who did it? (*personal*)	*What* was done? (*impersonal*)
We erected the towers.	*The towers* were erected.
You've made considerable progress.	*Considerable progress* has been made.
These scientists were doing research.	*Research* was being done.

To be controlled, to be built, etc.

A. We have to control locusts. B. Locusts have to be controlled.

The sentence A has the infinitive: *to control.*
The sentence B has the passive infinitive: *to be controlled.*

The passive infinitive is commonly found in the English of science, particularly in sentences that express:

Necessity, obligation. Referring to something which *needs* to be done, or must be done.

The factory has *to be built* by the river.
The pressure will have *to be reduced.*
The instruments need *to be sterilized.*
It is essential for the process *to be carried out* quickly.
There are several factors *to be considered.*

Intention, design, purpose. Referring to something which is intended, designed or planned to work in a certain way or at a certain time.

The results of the research are *to be published* soon.
This operation is not intended *to be finished* today.
This engine is designed *to be maintained* at low cost.
These containers are waiting *to be recharged.*

Likelihood, tendency. Referring to something which *may* happen.

More power is likely *to be needed* during the winter.

These crops are liable *to be attacked* by pests.
The blades of the turbine tend *to be eroded* by wet steam.

Allow, cause, enable, permit. The passive infinitive is very often used after these verbs in the following pattern:

This operation allows surplus energy *to be used.*
The heat causes the reaction *to be accelerated.*
The microscope enables small objects *to be observed.*
The machine permits the bags *to be filled* more rapidly.

The agent with the passive

Active	*Passive*
The surgeon performed the operation.	The operation was performed by the surgeon.
The assistant carried out the research.	The research was carried out by the assistant.

In these sentences the surgeon and the assistant are the people or agents who did the action. In the active sentences *the surgeon* and *the assistant* are the grammatical subjects, in the passive sentences they are the grammatical agents. The word *by* generally comes in front of the agent.

As the examples in the previous chapter show, because scientists prefer impersonal sentences, they do not normally mention the agent, if the agent is a person. The most common agents which occur in the English of science are:

Means, methods, ways of doing things

The fertilizer can be distributed by hand.
The problem was solved by intensive research.
Electricity can be transmitted by means of wires.
The reaction is helped by using a catalyst.
The solution is weakened by the addition of more water.

Notice *by means of* in front of the agent.

Animals, plants, substances

These crops are attacked by locusts.
The water is absorbed by the plant.
Decay is accelerated by enzymes.
The turbines are driven by steam.
The locusts are killed by the insecticide.
The damage was caused by fire.

Organisations, collections of people

Large quantities of fuel are used by modern industry.
New techniques have been developed by the research department.
Weather reports are prepared by the Meteorological Office.

Natural processes

The growth was affected by radiation.
The failure of the pipe was caused by corrosion.
The aerial was struck by lightning.

Circumstances, causes

Condensation is caused by the passage of a particle through the vapour.
The work was unaffected by the extent of the damage.

Inversion

We can sometimes start the sentence with the by-*phrase. This gives it extra stress, and is useful if we wish to draw special attention to the steps in an action or order of events:*

By the addition of water, the solution is weakened.
By using a catalyst, the reaction is helped.
By intensive research, the problem was solved.

We can also use By means of *to start a sentence:*

By means of wires, electricity can be transmitted.

(*Note:* We do not start sentences with *By* followed by single nouns, unless the nouns imply action. So we do not start sentences with *by wire, by hand, by the surgeon, by Mr. Jones*, but we may start them with *By analysis, By research, By manipulation*, if we wish to draw special attention to these actions.)

2. UNIVERSAL STATEMENTS

This piece of metal expanded when it was heated.
It will contract when cooled.

These sentences are *particular* statements about a particular piece of metal. But scientists assume that, in the past, metals always expanded when heated and contracted when cooled. They also believe that, in the future, metals will always expand when heated and contract when cooled. When scientists make statements

which they believe to be true at all times and in all places they use the simple form of the present tense.

Metals *expand* when heated and *contract* when cooled.

Statements of this kind are believed to be true *universally*, at all times and in all places.

Hydrogen *reacts* with oxygen.
Polymers *consist* of very large molecules.
The molecule of water *has* three atoms.

Other kinds of general or universal statements have the same form.

The laws of science

All masses *attract* each other.
Like charges *repel* each other. Unlike charges *attract*.

The present of the verb '*to be*' ('*is*', '*are*') is often found in the laws of science.

Action and reaction *are* equal and opposite.
Stress *is* proportional to strain.

Formulae equations

Written: $n(CH_2{=}CHCl) \rightarrow (-CH_2CHCl-)_n$
Spoken: *n*, C, H two, C, H, Cl *yields* C, H two, C, H, Cl, *n*

Written: $F = ma$
Spoken: Force applied equals mass times acceleration produced.

Written: $X \propto 1/y$
Spoken: *X varies* inversely as *y*.

Definitions

A bridge *spans* a gap.
An abutment *supports* one end of a bridge.
A diode valve *contains* two electrodes.
An isobar *is* a line drawn on a map between two points of equal atmospheric pressure.
The MKS unit of length *is* the metre.
The gram *is* the mass of one cc of water.
Cytology *is* the study of the cell.

These sentences define certain words. The definitions show how the words defined *are* used, and *will be* used.

'*Is*', '*are*' are more common in definitions than the simple form of the present.

Universal statements in the past and future

Cavendish showed that hydrogen *reacts* with oxygen to form water.
Newton *found* that all masses *attract* each other.
Will men discover that there *is* life on Mars?

Even when they are introduced by particular statements about the past or the future, universal statements remain in the present.

Happening now—happens regularly

We are now looking at another process. The heated plastics is being extruded through a die, in the form of threads. The threads are now being drawn through a bath, to cool them. Now they are being chopped into granules.

This is a spoken description of an industrial process. The speaker uses the continuous form of the present tense: *are looking, is being extruded, are being drawn, are being chopped.* This is the form generally used to refer to a process continuing or something which is not yet completed. But a scientist would probably describe the process in this way:

> We are now looking at another process. The heated plastics material is extruded through a die, in the form of threads. The threads are now drawn through a bath, to cool them. Then they are chopped into granules.

The first sentence still has the continuous form of the present tense. The speaker is drawing attention to the process. But the other sentences have the simple form of the present: *is extruded, are drawn, are chopped.* This is the form we use to describe a process which always happens in the same way. Scientists often use this form to describe a process because the process is intended to follow a definite sequence, and departs from the sequence only in unusual circumstances. Notice the use of *now*, showing that the process is actually going on, and in the last sentence the use of *then*, showing that we are looking at a later stage of this particular process.

Scientists also use the simple form of the present in this way when describing tests or demonstrations.

The chick embryos *are chopped up* and *are put* into a jar.
Then they *are poured* into a large flask. An enzyme *is added* to break down the tissue.

Continuous present

Scientists use the continuous form of the present tense informally in conversation.

Dr. Brown *is coming* from his office.
The operator *is opening* the door.
These containers *are waiting* to be recharged.

The continuous form of the present tense also occurs frequently in the formal impersonal English of science in:

Subordinate clauses

When *we are considering* problems of this sort, we need to keep in mind the cost of the operations involved.

Insecticides which *are being developed* will greatly reduce the risk of damage.
While the liquids *are reacting*, heat is evolved.

Descriptions of the progress of plans, projects, etc.

This year *we are testing* a new control system.
We *are obtaining* better results, but we *are still finding* this a difficult problem to solve and we *are being forced* to try other methods.

Descriptions of uncompleted actions and unfinished events

Plants *are being grown* outside.
It *is now becoming clear* that this method will not work.
From the start the turbine *is running* under control.

3. EXPRESSING PURPOSE AND FUNCTION

The distillation of crude oil is carried out *to separate* a number of fractions.

This sentence shows *why* the distillation of crude oil is carried out. It is about the *purpose* of distillation. A common way of expressing *purpose* is to use the infinitive of the verb. Scientists use the infinitive in this way to express *purpose, object or aim*: why something is done.

The object of reforming is *to produce high grade gasoline.*
This experiment is intended *to test the theory.*
The suspension is filtered *to remove the largest pieces of tissue.*

Design: why something is designed and made in a certain way.

The aircraft has been designed *to fly at 800 kilometres per hour.*
This equipment has been built *to work at very high altitudes.*
The bridge has been built *to support very heavy loads.*

Function: why something works in a certain way.

The powder acts as a catalyst *to speed the reaction.*
The pedal serves *to operate the clutch.*

Notice the use of the passive infinitive:

This engine is designed *to be run at high speeds.*

Notice that the infinitive can be put first:

To determine the number of cells, a specimen is placed under a microscope.

In order to. These words are frequently used before an infinitive in sentences of this kind:

In order to survive at this altitude, oxygen must be inhaled.

4. QUALIFYING WORDS

In scientific English a word which can be used as a noun is also often used as a word to qualify another noun. Consider the sentence:

The *oil tanker* carries *crude oil* to a refinery, where the oil is processed.

Here, *oil* appears first as a word which qualifies the noun *tanker* and, secondly, as a noun which is qualified by *crude.*

Similarly, *crude* can also be used as a noun, as in the sentence:

When the tanker reaches the *refinery* its load of *crude* is pumped into the *refinery storage tanks.*

Here, *crude* becomes a noun and *refinery* is used both as a noun and as a word qualifying *storage tanks.* The words *refinery*, *storage* and *tanks* could all be used as nouns, but in the sequence

refinery storage tanks

refinery and *storage* qualify the last word of the sequence, *tanks.* In English, words qualifying a noun always precede the noun.

Simple use: a single noun as a qualifying word

Cylinder head = the head of the cylinder.
Engine noise = the noise caused by engines.
Heat removal = the removal of heat.
Gas turbine = a turbine driven by a flow of gas.
Turbine gas = the gas in a turbine.

Compound use: a number of nouns and adjectives as qualifying words.

Cylinder head design = the design of the cylinder head.
Excessive engine noise = excessive noise caused by engines.
Heat removal plant = the plant for the removal of heat.
Main heat removal plant = the main plant for the removal of heat.
Advanced gas turbine generator = an electrical generator of advanced design driven by gas turbines.

-ing form: the *-ing* form of the verb used as a qualifying word.

Cleaning operation = an operation which cleans.
Heat removal plant cleaning operation = an operation for cleaning the heat removal plant.
Gas turbine generating station = a station for generating electricity by means of gas turbine generators.

Adverbs: adverbs used in groups of qualifying words.

Securely anchored cable = a cable which is anchored securely.
Increasingly heavy demands = demands which grow increasingly heavy.
Conveniently situated oil refineries = oil refineries which are situated in convenient places.
Considerably lower boiling point = point at which a substance boils which is considerably lower than some other points referred to.
Sufficiently rapid cooling process = a process of cooling which works with sufficient rapidity.

Proper names: the names of people used as qualifying words.

Kelvin scale = the scale invented by Kelvin.
Compton effect = the effect discovered by Compton.
Bessemer converter = the type of converter developed by Bessemer.
Bohr atom = the atomic structure proposed by Bohr.

Note that proper names are not used as qualifying words in the names of laws, theories, theorems or diseases.

Boyle's law	Maxwell's equations	Einstein's theory
Hooke's law	Newton's laws	Darwin's theory
Avogadro's hypothesis	Pascal's theorem	Mach's principle

and

Bright's disease	Parkinson's disease

5. SHORTENED SENTENCES

Because scientists need to be concise when they are writing for publications, they often shorten sentences which would normally be longer.

A. The signals are grouped into packages and a number of packages are combined into a composite signal.

B. The signals are grouped into packages and a number of packages combined into a composite signal.

Sentence B has been shortened by leaving out the helping verb *are* before *combined.*

Scientists often use sentences in which parts of verbs and other words have been left out. For example, clauses often occur in the English of science which have no helping verbs. Thus:

(1) When *they are* heated under pressure the constituents fuse together.

becomes:

When heated under pressure the constituents fuse together.

This sentence may be further shortened to:

Heated under pressure the constituents fuse.

(2) If *it is* alloyed with tin, copper forms a series of alloys *which are* known as bronze.

becomes:

If alloyed with tin, copper forms a series of alloys known as bronze.

or Alloyed with tin, copper forms a series of bronzes.

or Alloyed with tin, copper forms a bronze.

or With tin, copper forms a bronze.

Shortened sentences are particularly common in scientific writing. When talking, a scientist might describe a process using words which he would leave out in a written description.

Spoken description

(*a*) The steel is heated. *Then it is* quenched rapidly in water. *It is* heated again, and *this time it is* cooled slowly.

Written description

(*b*) The steel is heated, quenched rapidly in water, heated again and *finally* cooled slowly

which might become:

The steel is heated, quenched, re-heated and finally cooled slowly.

Spoken description

(*c*) The first programme would require a minimum of 108 weeks, *while* the second programme would *require* only 72 weeks.

Written description

(*d*) The first programme would require a minimum of 108 weeks, the second only 72 weeks.

6. SENTENCES WITH *IF*

If $d = 2$, then $d^2 = 4$

If the solution is cooled, then crystals will form.

The formula *If . . . then* is often used to indicate stages in an argument or an action. The content of the second part of the sentence follows and is dependent on the first.

If $x = a$, *then* $x^2 = a^2$.

If the patient dies, *then* the diagnosis is incorrect.

If our calculations are correct, *then* the space-craft should reach the moon on Friday.

If a solution is found, *then* proceed with the next stage.

If a decision is reached, *then* let me know.

In these sentences, the word *then* gives emphasis to the words that follow. It adds nothing to the meaning.

In sentences where such emphasis is not required, the word *then* is optional.
If this experiment fails, (then) the whole scheme must be scrapped.
If this problem is to be solved, (then) much more research needs to be done.

The word *then* is most often omitted when the subject in both parts of the sentence is the same.

If *methane* is cooled and compressed, *it* liquefies.
If *the beam* is subjected to a sudden load, *it* will break.
If *food* is not preserved, *it* will go bad.

Inversion
We can put the *If* part of the sentence to the end. When we do this, *then* is not used at all:

The whole scheme must be scrapped, *if* this experiment fails.
Let me know *if* a decision is reached.

Note that when the subject is the same in both parts of the sentence, the word *it* still comes second, for obvious reasons:

Methane liquefies, if *it* is cooled and compressed.
The beam will break, if *it* is subjected to a heavy load.

Negative
We can use *not* in either part of the sentence, or in both.
The engine will *not* run efficiently, if the correct fuel is *not* used.

If part of the sentence, we often use *unless* in place of *if . . . not*:

The engine will not run efficiently, *unless* the correct fuel is used.

Present
So far, every example has used the *present tense* in the *If* part of the sentence. This normally means that *either the present or the future* will be used in the other part.

If it *is cooled*, it *liquefies*. (Present)
If it *is used* in this way, it *will break*. (Future)

It is of course possible to use other tenses in the second part when the meaning demands it.

If the experiment fails, then you *have been* negligent.
If the results are negative, then the sample *was* faulty.

Possible alternative actions

We might put both parts of the sentence in the same tense to describe a series of possible alternative actions:

If we *looked* to the right, we *saw* the sea.
If we *looked* to the left, we *saw* the mountains.

In these sentences *If* has the force of *When*. By using *If* we imply a condition that existed. *When* implies a definite action.

What would *happen* if . . .?

Sometimes scientists wish to indicate the results of a possible or imagined course of action. They can do this by using *If* with the past tense, followed by *would*:

If the aircraft *flew* at 900 kph, it *would disintegrate.*
If the nerve *were cut*, no response *would be observed.*
These sentences do not refer to definite actions. They are suppositions.

1. We use *If it were* instead of *If it was* when the sentence is purely hypothetical.

Did it happen?

When speaking of something that happened in the past, scientists might wish to refer to the *possible* results of something, which did *not* happen, but might have done.

If the dam *had broken*, we *would have been killed.*
But the dam didn't break and so we were not killed. When this sequence of tenses is used, the action did not happen. It is only supposition.
If further tests *had been carried out*, the fault *would have been discovered.*
If my ideas *had been adopted*, this mess *would have been avoided.*

Note that *not* may be used in either part of these sentences, or in both.

If your ideas had been adopted, this mess would *not* have been avoided.
If prophylactic drugs had *not* been developed, the problem would have been more serious.
If you had *not* interfered, he would not have made this mistake.
Of course, when *not* is used in the *If* part of the sentence, the action *did* happen. The supposition is what would have happened if the action had *not* occurred.

7. 'TO BE' AND 'TO HAVE'

The following sentence patterns could all be found in scientific writing in English:

A. Tin resists corrosion by air or water.
B. Tin is resistant to corrosion by air or water.
C. Tin has a resistance to corrosion by air or water.

Sentence A ascribes an *activity* to tin—it *resists.*
Sentence B ascribes a *quality* to tin—it *is resistant.*
Sentence C ascribes a *property* to tin—it *has a resistance.*

The scientist can choose any one of these three sentence patterns. As we have seen, he usually prefers the shortest. But he will often prefer pattern B or C because they are more objective than A. The scientist tries to regard things, and even animals, as passive entities with certain qualities or having certain properties rather than as active agents. This attitude is naturally reflected in the sentence patterns he chooses. The patterns A, B and C are in order of increasing objectivity or formality.
Further examples:

Common salt *dissolves* in water.
Common salt is *soluble* in water.
Benzene *boils* at 80·4°C under normal pressure.
Benzene *has a boiling point* of 80·4°C under normal pressure.
This plastics material *is* more rigid.
This plastics material *has* greater rigidity.
The cross-section of the beam *is* I-shaped.
The beam has an I-shaped cross-section.
This specimen *is* 3·26 cm long.
This specimen *has* a length of 3·26 cm.
The storage vessel *can hold* 10,000 litres.
The storage vessel *has a capacity of* 10,000 litres.
The flowers of this plant *are* yellow.
This plant *has* yellow flowers.

List of Phonetic Symbols

1. VOWELS

Phonetic symbol	*Ordinary spelling of key word*	*Phonetic transcription*
iː	steel	stiːl
i	acid	ˈæsid
e	melt	melt
æ	graph	græf
aː	sample	saːmpl
ɔ	knot	nɔt
ɔː	cause	kɔːz
u	input	ˈinput
uː	plutonium	pluːˈtouniəm
ʌ	hull	hʌl
əː	curve	kəːv
ə	absorb	əbˈsɔːb
ei	scale	skeil
ou	flow	flou
ai	site	sait
au	powder	ˈpaudə
ɔi	oil	ɔil
iə	pier	piə
ɛə	compare	kəmˈpɛə
uə	ensure	inˈʃuə

2. CONSONANTS

Phonetic symbol	*Ordinary spelling of key word*	*Phonetic transcription*
p	pipe	paip
b	beam	biːm
t	tape	teip
d	deck	dek
k	kilocycle	ˈkiləsaikl
g	gas	gæs

CONSONANTS—*continued*

Phonetic symbol	*Ordinary spelling of key word*	*Phonetic transcription*
m	mass	mæs
n	normal	nɔːml
ŋ	tank	tæŋk
l	load, oil	loud, ɔil
r	random	ˈrændəm
f	feed	fiːd
v	vary	ˈvɛəri
θ	thermometer	θəːˈmɔmətə
ð	there	ðɛə
s	surface	ˈsəːfis
z	laser	ˈleizə
ʃ	shaft	ʃaːft
tʃ	discharge	disˈtʃaːdʒ
ʒ	equation	iˈkweiʒən
dʒ	jet	dʒet
h	heat	hiːt
j	insulate	ˈinsjuleit
w	weight	weit

The sign ˈ before a syllable shows that the syllable is strongly stressed.

Vocabulary

The words are also shown in phonetics (the International Phonetic Alphabet)

Note that * indicates that the sound 'r' is normally inserted when a word beginning with a vowel follows.

	Chapter number
A	
absolute [ˈæbsəluːt]	10
absorb [əbˈsɔːb]	2, 9, 10
absorbed [əbˈsɔːbd]	10
abutment [əˈbʌtmənt]	6
accelerate [əkˈseləreit]	5
accept [əkˈsept]	9
accurate [ˈækjurit]	10
accurately [ˈækjuritli]	9, 10
acid [ˈæsid]	1
acronym [ˈækrənim]	10
act [ækt]	3
act on [ˈækt ɔn]	3
activate [ˈæktiveit]	7
adjust [əˈdʒʌst]	2, 8
adjustment [əˈdʒʌstment]	8
advanced reactor [ədˈvaːnst riˈæktə*]	4
aerial [ˈɛəriəl]	12
aerodynamic [ˈɛəroudaiˈnæmik]	3
aerodynamically [ˈɛəroudaiˈnæmikli]	6
aerofoil [ˈɛərəfɔil]	3
affect [əˈfekt]	2, 9, 11
air-conditioning [ˈɛəkənˈdiʃəniŋ]	3
air-conditioning van [ˈɛəkənˈdiʃəniŋ ˈvæn]	3
aircraft [ˈɛəkraːft]	3
airfield [ˈɛəfiːld]	3
airframe [ˈɛəfreim]	3
airline [ˈɛəlain]	3
airport [ˈɛəpɔːt]	3
air pressure [ˈɛəˈpreʃə*]	3
airtight [ˈɛətait]	6
align [əˈlain]	12
alignment [əˈlainmənt]	12
in alignment [in əˈlainmənt]	12
out of alignment [aut əv əˈlainmənt]	12
alloy [ˈælɔi]; [əˈlɔi]	2, 6
altitude [ˈæltitjuːd]	3, 12
aluminium [ˌæljuˈminiəm]	6
amplify [ˈæmplifai]	10, 12
amplification [ˈæmplifiˈkeiʃən]	10, 12
amplifier [ˈæmplifaiə*]	12
amplitude modulation [ˈæmplitjuːd ˈmɔdjuːˈleiʃən]	12
analyse [ˈænəlaiz]	1, 9, 11
analysis [əˈnæləsis]	1, 2, 9
analytical [ænəˈlitikəl]	1
anchorage [ˈæŋkəridʒ]	6
anchored [ˈæŋkəd]	6
anode [ˈænoud]	7
apex [ˈeipeks]	12
apparatus [æpəˈreitəs]	7
apply [əˈplai]	1
applicable [əˈplikəbl]	1
application [ˈæpliˈkeiʃən]	1, 2, 5, 7, 9
applied [əˈplaid]	1, 11
applied science [əˈplaid ˈsaiəns]	7
arc [aːk]	12
arch [aːtʃ]	6
ash [æʃ]	4
assembly [əˈsembli]	8
atmospherics [ˈætməsˈferiks]	12
atom [ˈætəm]	1, 4, 5
atomize [ˈætəmaiz]	2
sub-atomic [ˈsʌb əˈtɔmik]	4
attain [əˈtein]	3
auto-tracking [ˈɔːtou ˈtrækiŋ]	12
automate [ˈɔːtəˈmeit]	8

	Chapter number
automated [ˈɔːtəˈmeitid]	8
automatically [ˈɔːtəˈmætikli]	7, 8, 9, 12
automatic blind landing [ˈɔːtəˈmætik ˈblaind ˈlændiŋ]	7
automatic control [ˈɔːtəˈmætik kənˈtroul]	7
automatic helmsman [ˈɔːtəmætik ˈhelmzmən]	8
automation [ˈɔːtəˈmeiʃən]	8
auxiliary power unit [ɔːgˈziljəri ˈpauə ˈjuːnit]	3
average [ˈævəridʒ]	11

B

baggage [ˈbægidʒ]	3
band [bænd]	12
bandwidth [ˈbændwidθ]	12
sub-bandwidth [ˈsʌb ˈbændwidθ]	12
base [beis]	1, 2, 5
basic [ˈbeisik]	5
basically [ˈbeisikəli]	5, 6
basis [ˈbeisis]	7
beam (of bridge) [biːm]	6
(of light)	7
(laser)	10
bearing (in machinery) [ˈbɛəriŋ]	10
bear on (rest on) [ˈbɛər ˈɔn]	6
behave [biˈheiv]	3
behaviour [biˈheiviə*]	1
berth [bəːθ]	8
billet mill [ˈbilit ˈmil]	2
binary [ˈbainəri]	9
binary digit [ˈbainəri ˈdidʒit]	9
binomial [baiˈnoumiəl]	11
binomial distribution [baiˈnoumiəl distriˈbjuːʃən]	11
bitumen [ˈbitjumin]	5
blade (of turbine) [bleid]	8
blast [blaːst]	2
blast furnace [ˈblaːst ˈfəːnis]	2
blend [blend]	5
block [blɔk]	2
anchorage block [ˈaŋkəridʒ ˈblɔk]	6
blow [blou]	2
blow moulding [ˈblou ˈmouldiŋ]	1
on board [ɔn ˈbɔːd]	3

	Chapter number
boiler [ˈbɔilə*]	8
boiling point [ˈbɔiliŋ ˈpɔint]	5
boost [buːst]	12
bore [bɔː*]	6
boron [ˈbɔːrɔn]	4
bow [bou]	8
bridge [bridʒ]	6
(of ship)	8
brittle [ˈbritl]	1
brittleness [ˈbritlnis]	1
bulb [bʌlb]	7
bulk [bʌlk]	9
in bulk [in ˈbʌlk]	9
bulk carrier [ˈbʌlk ˈkæriə*]	8
bulkhead [ˈbʌlkhed]	8
burner [ˈbəːnə*]	8
burn out [ˈbəːn ˈaut]	2
butt [bʌt]	8
buttress [ˈbʌtris]	6
by-product [ˈbai ˈprɔdʌkt]	4, 5

C

cable [ˈkeibl]	6, 12
coaxial cable [ˈkouæksiəl ˈkeibl]	12
calculate [ˈkælkjəleit]	10, 11
calculation [kælkjəˈleiʃən]	9
cambered [ˈkæmbəd]	3
cantilever [ˈkæntiliːvə*]	6
capable of [ˈkeipəbl əv]	3
capacitor [kəˈpæsitə*]	7, 9
carbon [ˈkaːbən]	2, 4, 5
carbon dioxide [ˈkaːbən daiˈɔksaid]	4
carbon monoxide [ˈkaːbən mɔnˈɔksaid]	2
cargo [ˈkaːgou]	3, 8
cargo container [ˈkaːgou kənˈteinə*]	8
carrier wave [ˈkæriə ˈweiv]	12
carry [ˈkæri]	7
cast [kaːst]	2, 6
catalyse [ˈkætəlaiz]	5
catalysed [ˈkætəlaizd]	5
catalysis [kəˈtæləsis]	5
catalyst [ˈkætəlist]	1, 5
catalyst regenerator [ˈkætəlist riˈdʒenəreitə*]	5
catalytic [ˈkætəˈlitik]	5

	Chapter number
catalytic cracking [ˈkætəˈlitik ˈkrækiŋ]	5
catalytic cracking unit [ˈkætəˈlitik ˈkrækiŋ ˈjuːnit]	5
catamaran [ˈkætəməˈræn]	8
cathode [ˈkæθoud]	7
cathode ray tube [ˈkæθoud ˈrei ˈtjuːb]	7
cause [kɔːz]	7
caused by [ˈkɔːzd bai]	3
centre [ˈsentə*]	3
chain reaction [ˈtʃein riːˈækʃən]	4
chance [tʃaːns]	11
channel [ˈtʃænəl]	12
channelled [ˈtʃænəld]	8
characteristic [ˈkæriktəˈristik]	1
charge (of furnace) [tʃaːdʒ]	2
(electrical)	4, 7
chemical [ˈkemikl]	4, 5
chemical industry [ˈkemikl ˈindəstri]	5
chemist [ˈkemist]	1
chlorine [ˈklɔːriːn]	1
chromium [ˈkroumiəm]	2
circuit [ˈsəːkit]	7, 8, 9
circulate [ˈsəːkjuleit]	4
civil engineer [ˈsivil ˈenʒiniə*]	6
clerical routine [ˈklerikəl ruːˈtiːn]	9
coal-fired [ˈkoul faiəd]	4
coat [kout]	8
cobalt [ˈkoubɔlt]	2
COBOL (COmmon Business Orientated Language) [ˈkoubɔl]	9
cockpit [ˈkɔkpit]	3
coding [ˈkoudiŋ]	9
coherent [kouˈhiərənt]	10
coke [kouk]	2
column (distillation) [ˈkɔləm]	5
combine [kəmˈbain]	1
combined [kəmˈbaind]	3
combine with [kəmˈbain wið]	2
communications [kəmˌjuːniˈkeiʃənz]	12
communications satellite [kəmˌjuːniˈkeiʃənz ˈsætəlait]	12
compact [kəmˈpækt]	10
compare [kəmˈpɛə*]	3, 11
component [kəmˈpounənt]	1, 2, 7, 9
compose [kəmˈpouz]	2, 12
composed of [kəmˈpouzd əv]	2
composite [ˈkɔmpəzit]	2, 12
composite signal [ˈkɔmpəzit ˈsignəl]	12
composition [ˈkɔmpəˈziʃən]	2, 5, 12
compound [ˈkɔmpaund]	1, 4, 5, 12
compress [kəmˈpres]	6
compressed [kəmˈprest]	6
compressible [kəmˈpresəbl]	6
compression [kəmˈpreʃən]	6
in compression [in kəmˈpreʃən]	6
compressive [kəmˈpresiv]	6
compressor [kəmˈpresə*]	6
compute [kəmˈpjuːt]	9
computer [kəmˈpjuːtə*]	8, 9
computation [ˈkɔmpjuˈteiʃən]	7, 9
concrete [ˈkɔnkriːt]	4, 6
condense [kənˈdens]	5
condensate [ˈkɔndenˈseit]	5
condensation [ˈkɔndenˈseiʃən]	5
condenser [kənˈdensə*]	5
condition [kənˈdiʃən]	9
conduct [kənˈdʌkt]	1
configuration [kənˈfigjuˈreiʃən]	3
conical [ˈkɔnikl]	12
consist of [kənˈsist əv]	2
constitute [ˈkɔnstitjuːt]	2
constituent [kənˈstitjuənt]	2
construct [kənˈstrʌkt]	6
constructed [kənˈstrʌktid]	6
construction [kənˈstrʌkʃən]	6
under construction [ˈʌndə kənˈstrʌkʃən]	6
constructional [kənˈstrʌkʃənəl]	6
constructor [kənˈstrʌktə*]	6
consumer [kənˈsjuːmə*]	4
consumer demand [kənˈsjuːmə diˈmaːnd]	4
consumption [kənˈsʌmpʃən]	4, 8
contain [kənˈtein]	2
container [kənˈteinə*]	2
content [ˈkɔntent]	2
continuous [kənˈtinjuəs]	2
continuous spray steelmaking [kənˈtinjuəs ˈsprei ˈstiːlmeikiŋ]	2
continuously [kənˈtinjuəsli]	8

	Chapter number
contraction [kən'trækʃən]	6
contractor [kən'træktə*]	8
contrast [kən'tra:st]	3
control [kən'troul]	3, 8
control rod [kən'troul 'rɔd]	4
control head [kən'troul 'hed]	8
control unit [kən'troul 'ju:nit]	9
controlled [kən'trould]	5
convert [kən'və:t]	2, 5, 7, 12
converter [kən'və:tə*]	2
conversion [kən'və:ʃən]	5
cool [ku:l]	4
coolant ['ku:lənt]	4
cooled [ku:ld]	9
cooling system ['ku:liŋ 'sistəm]	7, 9
co-ordinate [kou'ɔ:dineit]	11
copper pipe ['kɔpə 'paip]	2
core [kɔ:*]	6, 7, 9
core store ['kɔ: 'stɔ:*]	9
correlation [kɔri'leiʃən]	11
corrode [kə'roud]	1
corrosion [kə'rouʒən]	8
cost [kɔst]	2
capital cost ['kæpitəl 'kɔst]	2
initial cost [i'niʃəl 'kɔst]	2
running cost ['rʌniŋ 'kɔst]	2
unit cost ['ju:nit 'kɔst]	2
counteract ['kauntə'rækt]	3, 6
couple ['kʌpl]	8
course (at sea) [kɔ:s]	8
crack into ['kræk intu]	5
cracking (catalytic) ['krækiŋ]	5
craft [kra:ft]	8
crane [krein]	
crane capacity ['krein kə'pæsiti]	8
crew [kru:]	8
cross-section ['krɔs 'sekʃən]	6
cross-wind ['krɔs 'wind]	6
crude [kru:d]	5
crude oil ['kru:d 'ɔil]	5
cruising (speed) ['kru:ziŋ]	3
crystalline ['kristəlain]	5
non-crystalline ['nɔn 'kristəlain]	5
cube [kju:b]	8
current-path ['kʌrənt 'pa:θ]	7, 9
curvature ['kə:vətʃə*]	12
curve [kə:v]	11
cutting head ['kʌtiŋ 'hed]	8
cycle ['saikl]	12

D

dam [dæm]	6
arch dam ['a:tʃ 'dæm]	6
coffer dam ['kɔfə 'dæm]	6
fill dam ['fil 'dæm]	6
gravity dam ['græviti 'dæm]	6
data ['deitə]	9, 11
data logger ['deitə 'lɔgə*]	8
data store ['deitə 'stɔ:*]	7
deadweight (ship's loading including passengers, fuel and cargo) ['dedweit]	8
dB (decibel) ['di:'bi: ('desibel)]	12
deck (of bridge) [dek]	6
(of ship)	8
deckhouse ['dekhaus]	8
decking ['dekiŋ]	6
decompose ['di:kəm'pouz]	2
decomposed ['di:kəm'pouzd]	12
decrease ['di:kri:s]	7, 11
definite ['definit]	11
deflection [di'flekʃən]	12
deform [di'fɔ:m]	1
degradation [degrə'deiʃən]	12
densely ['densli]	9
density ['densiti]	1, 5
deposit [di'pɔzit]	5, 9
derive [də'raiv]	5
descriptive [di'skriptiv]	11
design [di'zain]	1, 3, 8
desirable [di'zaiərəbl]	11
develop [di'veləp]	1, 7, 9
development [di'veləpmənt]	1, 7, 9
deviation ['di:vi'eiʃən]	11
device [də'vais]	7, 8, 9
de-wax ['di: 'wæks]	5
diagram ['daiəgræm]	5, 11
diameter [dai'æmitə*]	2
diesel ['di:zl]	8
diesel fuel ['di:zl 'fjuəl]	5
digital ['didʒitəl]	9
dimension [di'menʃən]	7, 8, 9
diode valve ['daioud 'vælv]	7

	Chapter number
direct product [dai'rekt 'prɔdʌkt]	5
directional control [də'rekʃənəl kən'troul]	3
discharge [dis'tʃa:dʒ]	7
discrete [dis'kri:t]	11
dish (aerial) [diʃ]	12
dispersion [dis'pə:ʃən]	11
displacement [dis'pleismənt]	8
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weld [weld]	6
welding [ˈweldiŋ]	8
well (oil) [wel]	5
widely [ˈwaidli]	11
wing [wiŋ]	3
wire [waie*]	6, 9

Y

yardstick [ˈjaːdstik]	10
yield [jiːld]	5

Z

zero [ˈziərou]	11

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